CHEMICAL AND MINERALOGICAL PROPERTIES OF SOME SOILS FROM THE SUDAN GEZIRA, (AFRICA)

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CHAPTER I

INTRODUCTION

The dark clayey soils of the Central Clay Plain of the Sudan have several characteristics in common with the warm regions soils lately described under the Order Vertisol in the American System of Classification, 7th Approximation. Their lower categories however were not finally agreed upon particularly after the drastic change of this order. The Gezira is that area in the center of the plain extensively under irrigation mainly for the production of cotton which is the backbone of the national income of the country. Due to its importance the Gezira soil has received most of the research work conducted in this plain. Nevertheless, some problems remain to be solved. It may be appropriate to point out that there is not much variation between the Gezira soil and other areas within the plain. Therefore, information about any of them can be extrapolated to other areas provided that climatic and other local differences are considered. This paper is a modest contribution to the efforts being exerted to understand the behavior of these soils.

The main objective of this study is to show chemical, mineralogical and physical similarities or differences between two sites included in the same mapping unit and occurring far from each other and separated by different soils. The two sites are Tebub Block in Central Gezira and Unit 13 in Kenana extension. The information obtained might be helpful for further study of the Central Clay Plain soils. Most of these soils are under development or proposed for extension in the near future.

CHAPTER II

REVIEW OF LITERATURE

The Central Clay Plain of the Sudan as the name denotes occupies the central part of the country in between longitudes 30^{o} - 37^{o} and latitudes 10^{o} - 16^{o}. It is one of five soil regions well defined across the Sudan as a result of remarkable climatic and other soil forming variables (1).

Topography and Geology

The area is a vast plain of deposition with very gentle slopes. The overall slope of the land westwards from Singa to the White Nile (from east to west) is 30 cm per kilometer and the differences in level between Khartoum (extreme North) and Malakal (extreme South) is approximately 7 meters, the two cities are 440 kilimeters apart. The plain is interrupted by a few mountains of basement complex rocks. The majority of the soil parent material was laid down on basement complex rocks with some areas deposited on Nubian sandstone like the Eastern Gezira or on Red Sea coastal deposits similar to soils sources of the White Nile extending Northwards from Malakal to Jebelen (43).

Climate

The plain has a typical tropical continental climate with a rainfall increasing from North to South. In the North the annual rainfall is about 200 mm/yr and increases to as much as 800 mm/yr in the South.

The effective rainfall occurs within a period of about 4 months and for the rest of the year the plain is left dry. The weather is very stable during the dry season but occasional intense storms occur in summer. There is little variation in temperature on the plain. The mean annual temperature is 28.5° C. (82° F.), mean maximum 36.7° C. (96° F.), and mean minimum 20.6° C. (68° F.) (43).

Vegetation

The vegetation was studied by F. W. Andrews (43) and summarized under the following regions:

Accacia Desert Scrub Region

This area, which includes the northern part of the Gezira, has a rainfall of less than 12 inches/year. Shrubs and trees are plentiful with dominance of *Accacia spp*. The vegetation is scattered and areas may occur without trees. *Accacia Orfata* 'Laot' was noted on lighter soils and *Accacia Mellifera* on heavier soils. Other common trees are 'heglig' (*Balanites aegyptiaca* Del.), 'sidr', 'usher' (*Salvandora persica* Linn.), 'haraz', and 'talh'. Of the grasses 'tumam', 'nal' and 'haskanit' (*Cenchrus biflorus* Roxb.) were reported. Among climbing plants 'salal' (*Cinus quandrangullus* Linn.) is the most conspicious.

Accacia Short-Grass Scrub Region

This area is characterized by higher rainfall than the preceeding region (12 to 20 inches) which is sufficient to mature many grasses and herbs. *Accacia* is still the dominant species with greater variety and broader leaved trees. Grasses, herbs and scattered patches of 'kitre', 'laot', 'sidr', and 'tumam' are common in the irrigated Gezira area and may be considered as a typical vegetation of Tebub Block.

Accacia Tall-Grass Forest Region

This region is characterized by a rainfall of 20 to 40 inches/yr and a vegetation quite distinct from the preceeding regions. Accacia is still prominent with broad leaved trees and other species. 'Talh', 'hashab', 'heglig' and non thorny trees are abundant. Most of Kenana area is under these kinds of vegetation.

Description of the Soil

The plain is formed of heavy alkaline deep cracking soils of considerable depth. The deposit extends over a vast area without showing clear profile differences. However, G. A. Worrell (45) has reported some gradual horizonation change. He found at the southern margin of the Gezira area the soil grades naturally into a wider and deeper cracking soil of lower salinity, lower alkalinity, less differentation of profile horizons and of no or little gypsum. He concluded that these differences can not be attributed to climatic differences only as might be suggested by the increasing rainfall from North to South because the same trend of change was observed to the eastern extension of the Gezira which has more or less the same amount of rainfall. The less horizonation was explained by H. Green (19) and discussed under Genesis of Gezira soil.

The same author (19) has described and sketched a typical Gezira profile as follows (Fig. 1): The surface soil to a depth of two feet is dark brown. Below it there is a layer of gray soil penetrated by tongues of brown soil, and below the gray layer the soil is yellow brown. The horizonation of the profile is not abrupt as the diagram may suggest, but nevertheless can easily be followed by careful inspection. Tongues of the top brown layer in the subsoil was explained

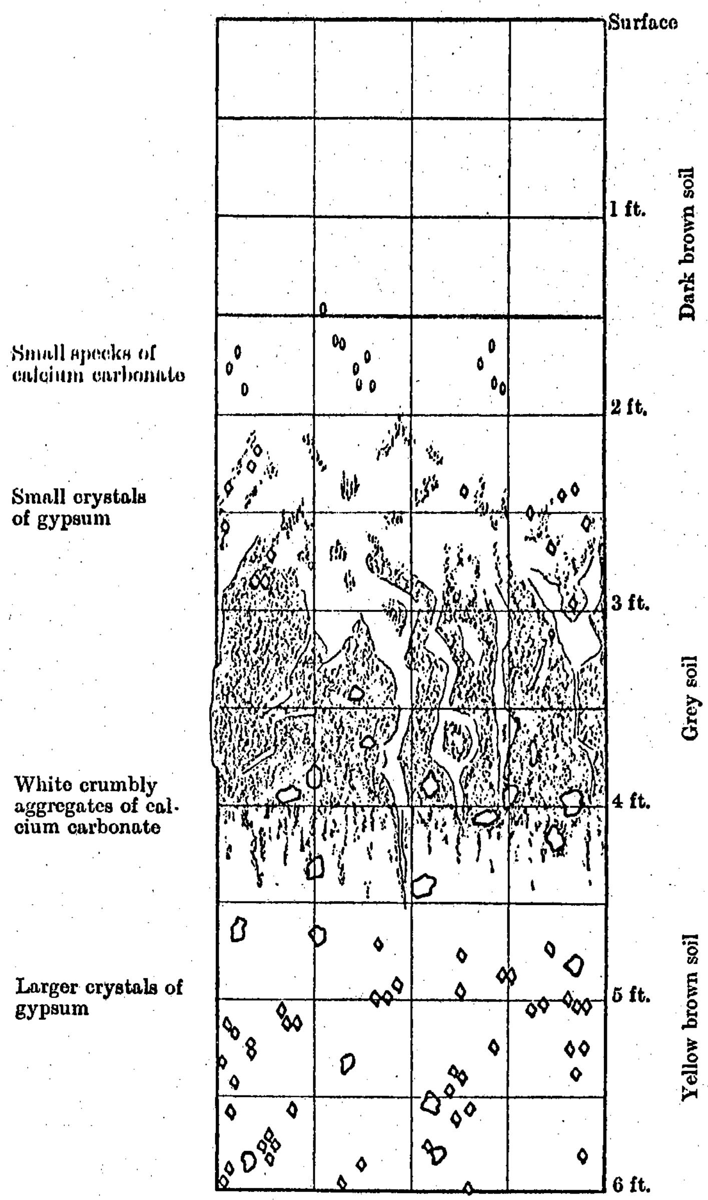

Figure 1. Diamgrammatic Representation of Soil Profile at the Gezira Research Farm. After Green. (Soil Profile in the Eastern Gezira. J. Agric. Sci. 18: 518-530.)

by T. N. Jewitt (27) as a result of surface soil falling down into the deep cracks. The upper limit of the gray layer is characterized by the occurrence of small crystals of gypsum. Its lower limit however coincides with accumulation of white concretions of calcium carbonate about one inch in diameter. Gypsum occurs again in considerable amount below the lower zone of accumulation of $CaCO_3$. Throughout the profile nodules of calcium carbonate are present, near the surface they are black due to manganese coating and at lower depths they are white. Recently, Blockhuis, Ochtman and Peters (6) briefly described a typical Gezira and Khashm el Girba profile as follows:

> The soils on both plains are very similar in appearance throughout the solum. The clay percentages vary between 50 and 70%, silt between 15 and 30%, fine sand between 10 and 20%, while coarse sand is almost absent. The clays belong to a pseudo-chloritic transitional montmorillonite-illite series, in one case the illitic character is predominant, in another the montmorillonitic character. In Khashm el Girba there is a tendency toward illite being more important in the subsoils and some sort of montmorillonite in the surface layers. A profile in the Gezira, near Wad Medani, has clays more consistently composed of pseudochloritic montmorillonite.
>
> The cation exchange capacity is approximately 1 milliequivalent/g of clay. Throughout the soil calcium is the dominant cation on the exchange complex; in the 0-30 cm layer sodium occupies in general 10-15% of the exchange sites. The organic matter, though low in content (0.3 - 0.5%C), is a mull; the C/N ratio increases with depth and varies between 10 and 15.
>
> The soils swell upon wetting and shrink upon drying; they are generally self-mulching and there is some churning, but only occasionally a true gilgai-microrelief is found.
>
> The solum consists of a dark yellowish brown (10 YR 3/4 moist) surface soil, 7-90 cm thick (A1) overlying a dark grayish brown (10 YR 3/2, moist) soil layer, 50-80 cm thick with an accumulation of powdery calcium carbonate and fine crystalline gypsum (Acacs) or calcium carbonate alone (Aca). Calcic and gypsic horizons occur in the substratum. The solum is free of mottling but in the substratum some mottling may occur. There is an ochric epipedon.
>
> The soil exposed in the wall of a pit shows a tendency towards a horizontal lamination; the finest structural elements are wedges of parallelepiped aggregates. Slickensides occur in the lower part of the solum and in the substratum.

Genesis

Several theories have been forwarded to explain the mode of formation of the Central Plain. The most attractive is that the plain was partly deposited from the Blue Nile and partly by the White Nile from two different rock sources. This hypothesis was supported by Tothill (43) who claimed that the Gezira and other areas to the East of the plain are of Blue Nile origin while areas to the West and Southwest are of White Nile origin. To explain how Gezira soil was deposited he stated that during its formation this part of the plain might have dried out annually as evidence by the vertical and lateral distribution of Ampullaria and Lanistes remains. The two amphibius species breathe by both lungs and gills and inhabit today regions that normally are covered with rains or flood water for several months of the year. On this account and in the absence of shells that characterize a lake condition, he rejected both eolian and lacustrine origins. He explained the different origin of the Whie Nile soils by the presence of gypsum in Gezira profile. He reported that although gypsum is a characteristic of water generally it is only deposited in the presence of sodium carbonate which is abundant in the Blue Nile water. However recently the staff of the soil survey project has detected gypsum in considerable amounts in some soils believed by Tothill to be of White Nile origin. It seems that a study of the heavy minerals of different soils across the plain will give more useful information relative to the origin of these deposits. This was initiated by some geologists in the United Arab Republic (38). They studied the mineralogical composition of the River Nile and its tributaries. Their work was not directed to solve problems of Sudanese soils yet proved to be helpful in this line. They found that the different tributaries of the Nile possess different characteristic mineral assemblages. The Blue Nile is characterized by abundance of augite while the White Nile southern tributaries (El Ghazal, El Gebel, and El Sobat) are characterized by an abundance of metamorphic minerals such as silliminite, kyanite and staurolite. This three metamorphic minerals occur as traces in the Gezira profile (see Mineralogy, Appendix Table XVI), while other minerals like augite, hornblend and epidot, widely distributed in igneous rocks, are abundant. Knowing that the Blue Nile flows from a region of basic igneous rocks in the high lands of Ethiopia one is inclined to favor a Blue Nile origin to the Gezira and perhaps other areas within the plain reported by Andrew (43) to be of the same origin.

Andrew (43) reported that the Blue Nile sediments extend as far as the left bank of the White Nile at Jebel Auliya and into the central part of the Gezira plain, midway between the Blue Nile and the White Nile in latitude 14^{o} 45 N. The southern limit of the Blue Nile sediments south of Khartoum has not yet been exactly ascertained. About the White Nile deposits, little is known, but they seem to extend from the Ethiopian frontiers south of Roseiris to the Western side of the Nuba Mountains, South of the Sennar-Kosti railway to the South of the Sebat and round the edge of the Sudd swamps.

The less distinction of horizons observed in the southern extension of the plain was described by Green (19) to mixing of the soil in the following manner. The plain receives two-thirds of its annual rainfall within only two months and is left dry for a long season during which deep, wide cracks develop. During the hot months of April, May and June wind lifts and transports loose material sloughing it deep into these cracks. In this manner the top brown soil is washed down and the gray layer is brought nearer to the surface. It seems obvious from this concept that the magnitude of climatic conditions mainly rainfall and wind is the factor controlling distinction of horizons in the soil profile.

Chemical and Physical Properties

Salinity

Salinity increases from South to North and from East to West. It also occurs as localities on the plain as shown on the map of the Gezira area (Appendix Fig. 8). Vertically the soluble salts increase with depth to a maximum within the gray compact layer. In profiles without clear horizonation, as reported by Blockhuis (5), in some Kenana soils soluble salts increase to reach a maximum at about 150 cm.

Expression of soluble salts as percentages as shown on the map and as reported by several workers though good enough for comparison purposes is misleading when related to the actual concentration of salts in the soil solution and its osmotic pressure. This is due to differences in texture as it affects the water holding capacity of the soil. For example, Richards (44) has shown that all crops can make good growth below an electrical conductivity of about 4 millimos per cm. at 25^{o} C. This conductivity corresponds to about 0.2 percent salts in a clay soil that has a saturation percentage of about 75. However, in a sandy soil for which the saturation percentage is 25 a 0.2 percent salt corresponds to an electrical conductivity in the saturation extract of 12 millimohs per cm. at 25^{o} C., which is too saline for good growth of most crop plants. In the central plain texture variation is not high enough to affect seriously the interpretation of salinity on field crops; nevertheless conductivity gives more reliable interpretations. Areas with high salinity were excluded from irrigation when the cultivation of cotton started about 1920 in the Central Clay Plain of the Sudan. However, new criteria are being used (15) to select new areas for development as the content of salinity alone did not give satisfactory results. Recently it was found that even with large amounts of irrigation water soil salinity development was not the major cause of low yields of cotton in the Gezira and the Managil extension.[1] However, a detailed study directed towards showing reduction in yield of cotton and other crops was not undertaken. With the intensification and diversification programs expected in this area a review of some practical salinity problems may be desirable.

Generally plants show a progressive decline in growth of leaves, stems and roots as levels of salinity increase. Bernstein (4) has shown that in sensitive plants like corn, alfalfa and beans yields are decreased in proportion to decrease in plant size. With more tolerant plants like cotton, wheat and barley, however, the yield may not decline even when salinity causes a decrease of as much as 50 percent in plant size. Salinity may introduce some nutritional problems. For example, high concentrations of calcium ions in the soil solution may prevent the plant from absorbing enough potassium. This nutritional effect however is not important in most crops under most saline conditions. Sodium and chloride ions when present in high amount in the soil solution may be toxic and cause acute injury particularly to grapes, citrus and other fruits.

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[1]Rahad Pre. Appraisal Report. Private communication.

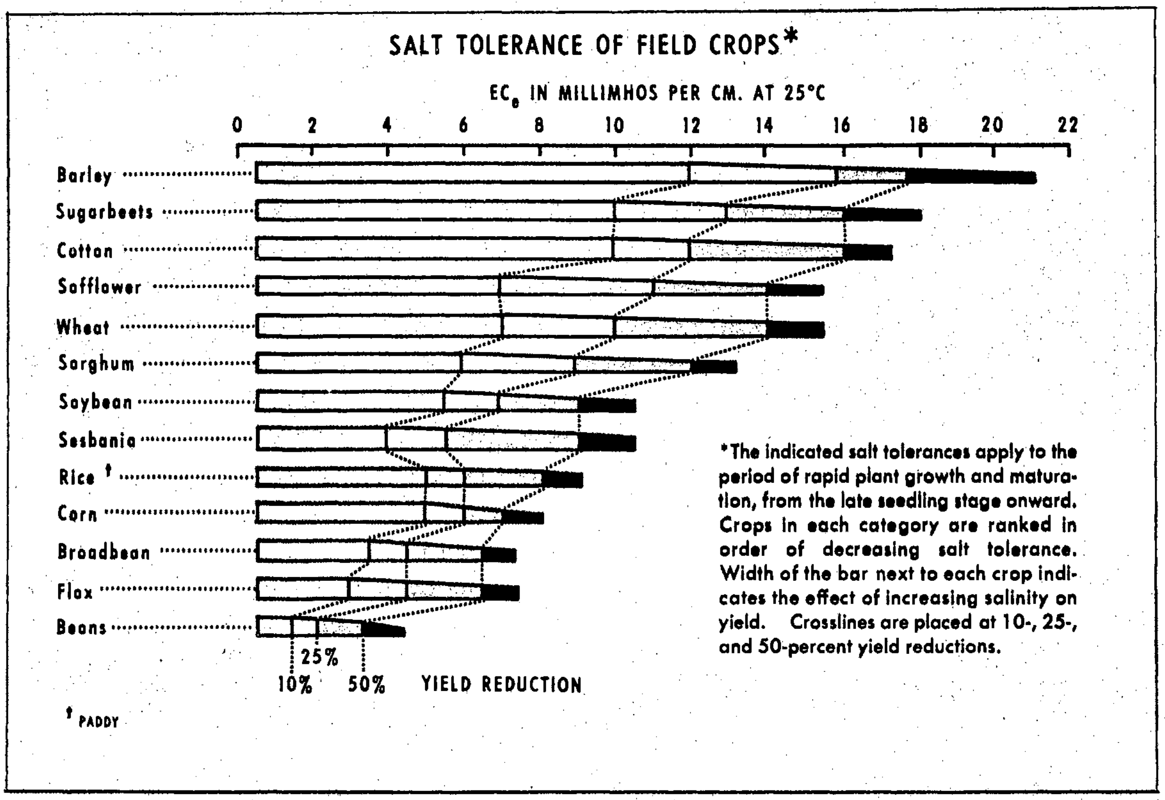
From his experiments in artifically salinized field plots, Bernstein (4) has plotted diagrams, as shown in Fig. 2 and Fig. 3, to show salt tolerances of important crop plants.

One serious effect of high salt content is that water entry into roots is restricted by the solute suction of the soil solution. Dissolved salts have an attraction for water and oppose its absorption by plant roots. As stated before this osmotic effect on solute suction depends not only on the amount of salt but also on the amount of water in the soil at the same time. In other words, it also depends on the capacity of the soil to hold water. Solute suction is not the only factor that restricts the uptake of water by plants. Matric suction is also important and the combined effect of both suctions is referred to by Richards (44) as total suction. Matric suction is due to attraction of water on the surface of the soil matrix. It is a measure of the tenacity with which water is held on the surface of the soil particles and depends on the thickness of the water films, i.e., in the amount of water.

The total suction determines availability of water to plant roots in the presence of soluble salts. Therefore, it may be concluded that the rate of growth of crop plants decreases as the total suction of soil water increases if other factors are favorable.

Alkalinity

Alkalinity in this plain is more important than salinity to evaluate the soil in relation to the production of cotton. It comes next to clay content as a criterion of land capability classification. However despite the high exchangeable sodium it has been observed that the surface soil retains some permeability and remains flocculated. The



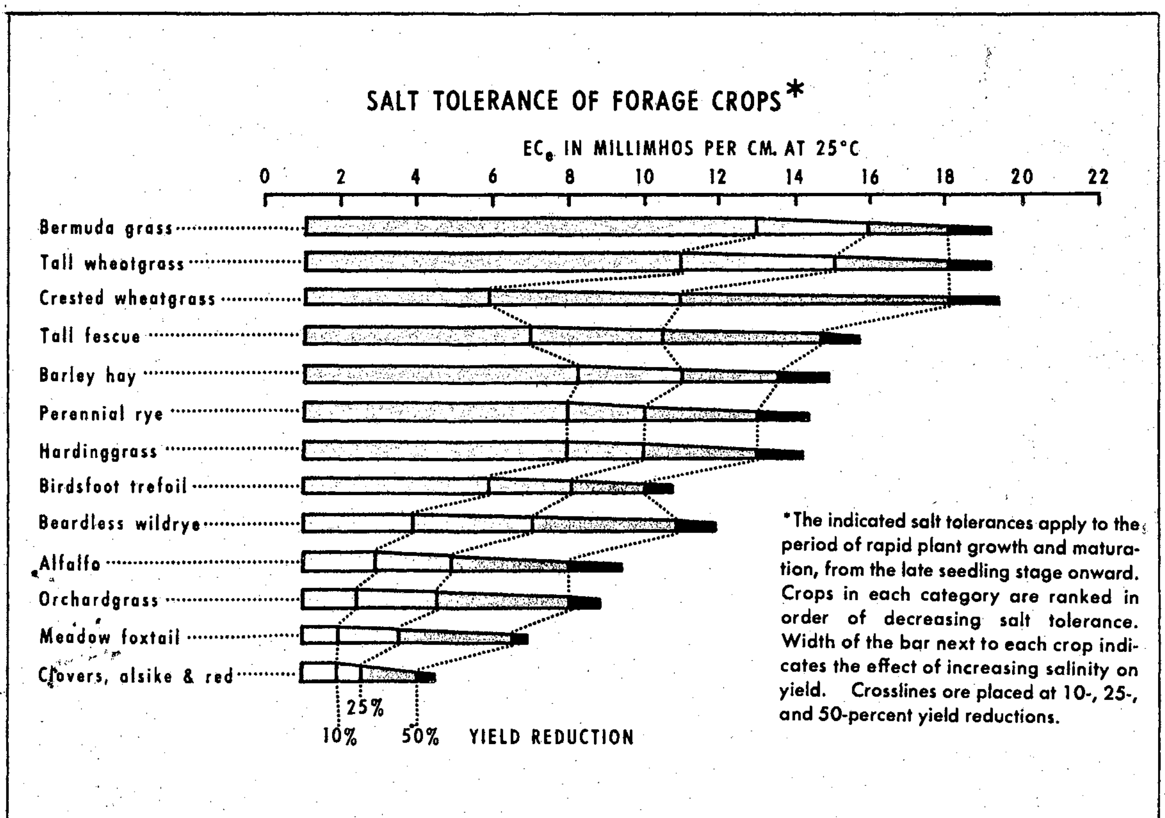


Figure 2. Salt Tolerance of Field and Forage Crops. After Bernstein (Salt Tolerance of Plants. U.S.D.A. Agricultural Information Bulletin No. 283. U. S. Printing Office, Washington, D. C. 1964)

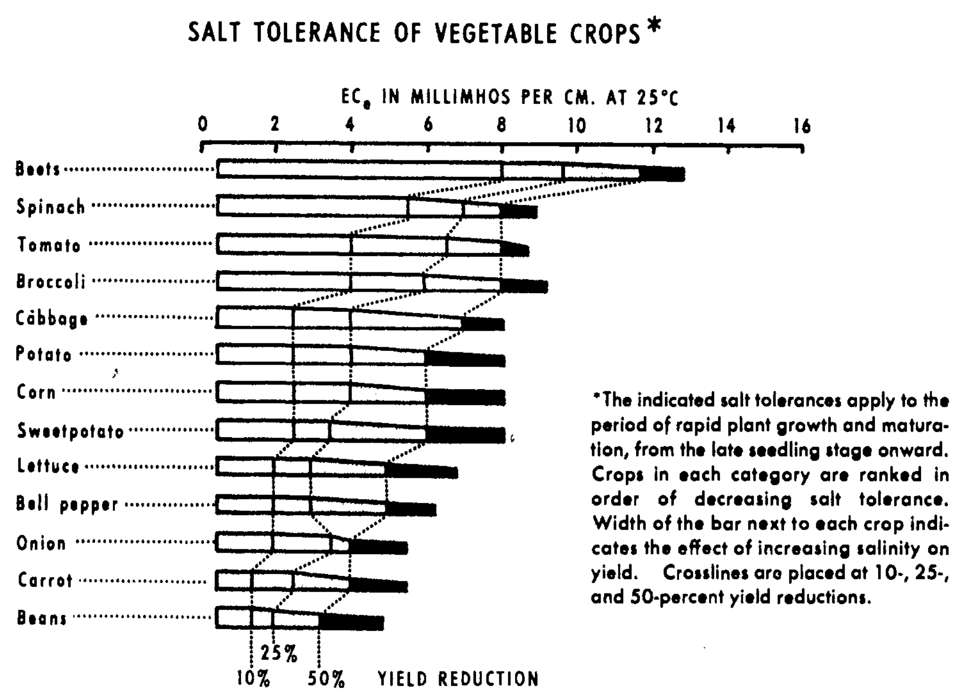


Figure 3. Salt Tolerance of Vegetable Crops After Bernstein (Salt Tolerance of Plants. U.S.D.A. Agricultural Information Bulletin No. 283. U. S. Printing Office, Washington, D. C. 1964)

work of Eaton and Sokoloff (13) may partly explain this anamolous behavior. They found that calcium may come into solution from calcium carbonate or gypsum. Therefore if the soil profile contains these sparingly soluble salts and a high quality irrigation water is used, calcium in the aqueous phase is momentarily increased. With this increase in calcium relative to sodium adsorbed sodium is replaced and continues to be replaced by more calcium from gypsum, calcium carbonate or from irrigation water if it has appreciable quantities of dissolved calcium. Gypsum and calcium carbonate are very common in soils of the Central Plain and the Blue Nile water is of a high quality with a Ca/Na of about 4.2. Under the high pH of the soil, however, calcium carbonate is not expected to go into solution and enrich the aqueous phase with Ca^{++}.

The permeability of the surface soil might therefore be attributed to an exchange phenomenon where sodium is replaced by calcium which is introduced by irrigation water and gypsum. It seems that with more irrigation more sodium can be removed and deeper percolation may be achieved. On the other hand the permeability of the soil in the prescence of high exchangeable sodium may be due to error encountered in the determination of adsorbed sodium. Over estimation of adsorbed sodium was reported on some California soils by Babcock (2). He showed that a solid form of sodium salt may be present in the soil which dissolves in normal extracting solutions but not in water. In other words when a soil is treated with NH_4Ac, for example, this solid sodium compound goes into solution and is measured as extractable or exchangeable sodium. Therefore, when soluble sodium of the saturation extract is subtracted from extractable sodium to calculate exchangeable sodium an overestimation of adsorbed sodium is obtained and erroneous conclusions about alkalinity levels may be made. Bower and Hatcher (7) have presented some data to show that the determination of exchangeable sodium percentage (ESP) by the method of Bower et al. (9) results in appreciable errors under the following three conditions: (a) when salinity is high negative adsorption causes lower values of exchangeable sodium; (b) when the soil contains forms of sodium which are not readily water soluble or exchangeable but dissolve or decompose in NH_4Ac; and (c) exchangeable sodium not replaced by the relatively large fixable NH_4 ion. Kelley (28) criticized the methods of determination of ESP and raised the following important points: (1) in the determination of CEC, if the extracting solution is pronouncedly alkaline chemically, the total amount of cations adsorbed from the solution is frequently much greater than from a neutral solution; (2) With the use of N·Na acetate adjusted to pH 8.2, as in the method of Bower et al. (9), one can hardly expect accurate results because many alkali soils are much more alkaline than pH 8.2 (3) The difficulty found by various workers to correlate the growth of plants in non saline alkali soil may partly be due to the influence of precipitated substances, particularly calcium compounds (29). Finely divided calcium compounds intimately disseminated through the soil and Ca^{++} adsorbed at high pH probably influence the effect produced on growing plants by adsorbed Na+, and this effect may be considerable (29). More research work in alkalinity is required to ascertain whether any of the previously discussed conditions is operative in the soils of the Central Plain of the Sudan.

If one does not concern himself with the complexity of the methods of determination, Pearson (37) established a relation between alkalinity and tolerance of various crops as shown in Table I.

Physical Properties

Bulk Density

A dense layer has long been recognized to occur in the sub-soil of the Gezira profile and other extensions. The depth of this layer from the surface as well as its density were thought to be limiting factors in cotton yield. Some cotton plants were found with their roots distorted after hitting this hard layer. The development of the roots was consequently much restricted. By loosening the profile to a depth of one meter in an experiment at the Gezira Farm root penetration was very much increased. In an attempt to compare the Sudanese soil Gezira, Rohad and Dinder with the American soil Houston, Beaumont and Imperial, a similar peculiar behavior was observed by the author of this paper. The Sudanese soils have higher hydraulic conductivity as measured in a disturbed sample though their clay content and SAR or ESP are higher than values obtained from the American soils. Some of the values are shown on Table II. Deep plowing was suggested to increase root development and water penetration but for how long the effect of this operation remains effective is not yet ascertained. It has been found however that the effect of deep tillage disappeared in some soils within 1 year (39).

Table III shows bulk density for a high and low productivity soil in the irrigated Gezira area. Higher values were obtained during this study for Kenana and Tebub Block soils using the elastic saran resin as a coating material. These are shown in Chapter IV, Results and Discussion. It does not appear from these results that mechanical impedance of roots is due to formation of traffic pans. Traffic pans usually

TABLE I

TOLERANCE OF VARIOUS CROPS TO EXCHANGEABLE-SODIUM-PERCENTAGE AFTER PEARSON (37)

Tolerance to ESP[1] and Range at Which Affected	Crop	Growth Response Under Field Conditions
Extremely sensitive (ESP = 2-10)	Deciduous fruits..... Nuts................. Citrus............... Avocado..............	Sodium symptoms even at low ESP values.
Sensitive (ESP = 10-20)	Beans................	Stunted growth at low ESP values even though the physical condition of the soil may be good.
Moderately tolerant (ESP = 10-20)	Clover............... Oats................. Tall fescue.......... Rice................. Dallisgrass..........	Stunted growth due to both nutritional factors and adverse soil conditions.
Tolerant (ESP = 40-60)	Wheat................ Cotton............... Alfalfa.............. Barley............... Tomatoes............. Beets................	Stunted growth usually due to adverse physical condition of soil.
Most tolerant (ESP = more than 60)	Crested and Fairway wheatgrass.......... Tall wheatgrass...... Rhodes grass.........	Do

TABLE II

HYDRAULIC CONDUCTIVITY OF SEVERAL HIGH-CLAY SOILS

	ESP	cm. per hour	
		0 - 100 ml.	100 - 500 ml.
Gezira	13	1.85	1.38
Rahad	6	1.43	1.25
Dinder	0.5	.99	.83
Houston	0.3	.67	.22
Beaumont	1.6	.23	.27
Imperial	-	1.53	.86

TABLE III

BULK DENSITY FOR A HIGH AND LOW PRODUCTIVITY SOIL
IN THE IRRIGATED GEZIRA AREA

Depth, Cm	High Production Soil	Low Production Soil[1]
0 - 30	1.21	1.45
30 - 45	1.28	1.45
45 - 75	1.36	1.52
75 - 105	1.47	1.61
105 - 140	1.47	1.65
140 - 170	1.37	1.51
170 - 190	1.40	1.51

[1] Annual Report, Gezira Research Station 1961/62, Wad Medani Sudan. Personal communication.

show a sudden change in bulk density between the plow layer at about 7 inches and the underlying pan. They again show a contrast in bulk density below the traffic pan (39). In the Central Clay Plain despite the presence of a slightly denser subsoil the whole profile is compacted down to a depth of 2 meters or more. This can hardly be due to traffic which is not heavily and frequently used in this plain.

Swelling, Shrinking and Cracks Development

In general, cracks are considered one of the important characteristics of Vertisols. In the Central Clay Plain of the Sudan their importance is increased because they are more effective in controlling the water content of the soil than infilteration rate through an imperfectly drained profile. It has also been observed that after the cracks are sealed very little water can find access to the subsoil. Therefore the relation found between clay content and cotton yield may probably be due to cracking. High clay content results in extensive cracking which increases the uptake of water by the soil. Following is a review of the mode of formation of cracks as visualized by Johnston and Hill (28) and related to the swelling-shrinkage phenomenon. They stated that shrinkage is a result of drying out which produces cleavage planes. These planes continue to widen as the soil body dries and shrinks. With more drying and shrinking the cleavage planes develop in the so-called dry weather cracks. These cracks can strike in any direction, horizontally, vertically and at all angles taking the direction of weakness. These directions coincide with points of highest moisture content because the soil becomes harder and harder as the moisture content decreases. The direction of cracks is of course important relative to water content particularly of the root zone. It seems therefore that a study of the cracking patterns, swelling and shrinking of the Sudanese vertisols may help in solving some of their problems associated with moisture conservation, tillage operation, and land capability classification. It may also help in the evaluation of soils even for engineering purposes. It has also been pointed out that formation of crack results in a decreasing moisture supply by exposing the soil to direct evaporation and desiccation. Vegetation was also found to influence the pattern of cracking. Different patterns were observed in the same soil under cotton, sorghum and when the land is left fallow. Though the reason is not clearly understood, the mode of moisture depletion under these three different conditions has been studied by Johnston and Hill (28). Soil under cotton grown in rows shrinks towards the row and cleaves at the point of least resistance which is the area between the rows. They also concluded that wetting and drying accompanied by swelling and shrinking are necessary to disintegrate clodding of the soil and to form a granular soil structure. The surface mulch of some soils in the Central Clay Plain may partly be ascribed to this natural process which can be accelerated by tillage operations such as discing to prepare a desirable seed bed. In connection with the management of swelling soils it has also been shown that plowing causes the soil to become cloddy particularly if heavy tractors are used and the field moisture was low. Such practices deteriorate the physical properties of the soil and introduce difficulties in the preparation of a good seed bed.

Irrigation Water

The Blue Nile is the main source of water for irrigation of that part of the Central Clay Plain bounded by the Blue and White Niles and including the largest agricultural areas in the Sudan, the Gezira, Managil and Kenana. Some other areas to the East, proposed for cultivation will also be irrigated with the same water. On this basis the Blue Nile has been most important for Sudanese agriculture and it has been sampled for analysis since the early days of soil research in the Sudan about 1917. Beam, Green and Snow (27) have investigated the composition of the water and reported a calcium/sodium of 4.2. The most recent and elaborate analysis was given by U. S. Salinity Laboratory at Riverside, California as shown in Table IV.

Using the method suggested for the classification of irrigation water by Richards et al. (44) the Blue Nile water can be classified as C1-S1, i.e., low salinity water. Water of this class can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. This classification is based only on the electrical conductivity and SAR. It does not consider other harmful effects from bicarbonate and boron, for example.

Being very toxic boron should be considered in assessing the quality of irrigation waters. According to the limits proposed by Scofield (44) the Blue Nile water with regard to boron can be classified as Class I. Under irrigation with waters of this class even sensitive plants are not affected. The effect of the bicarbonate ion is expressed in terms of the residual sodium carbonate (RSC). Eaton (13) defined this value in the following equation:

$$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg)$$

in which the concentration is expressed in milliequivalents per litre. The bicarbonate ion tends to precipitate calcium and magnesium in the soil solution. Sodium hazard therefore is increased. The Blue Nile

TABLE IV

ANALYSIS OF BLUE NILE WATER

Conductivity, EC X 10^6 at 25° C	152
Soluble Sodium percentage (SSP)	15
Sodium adsorption ratio (SAR)	0.3
Boron (B) ppm	0.04
Dissolved Solids:	
ppm	118
ton per acre-foot	.16
pH	7.9
Silica (SiO_2) ppm	10
Cations meq/L	
Calcium (Ca)	1.01
Magnesium (Mg)	0.34
Sodium (Na)	0.24
Potassium (K)	0.04
Sum	1.60
Anions meq/L	
Carbonate (CO_3)	0
Bicarbonate (HCO_3)	1.45
Sulfate (SO_4)	.12
Chloride (Cl)	0.03
Fluoride (F)	0.03
Nitrate (NO_3)	0.01
Sum	1.64

water has a RSC of .14 which is safe for most purposes as found by Wilcox et al. (44).

From the foregoing the Blue Nile water can successfully be used for irrigation without developing problems in the foreseeable future. However, it should be remembered that the limits given before are assumed to give reliable results under average conditions of soil texture, infilteration rate, drainage climate and tolerance of crops. Therefore, large deviations from these average conditions may necessitate modification of this classification.

Mineralogical Properties

The mineralogical analysis of the coarse fraction of some Gezira soils is shown in Appendix Table XVI. More important is their clay mineralogy. Their characteristics are mainly influenced by this inorganic fraction. Today many practical problems in soil management are more apt to be solved as a result of knowledge of the mineralogical composition of the soil. The type of clay minerals was found to affect fixation of K, P, and N and to control the moisture, temperature and nutrient supply. Therefore, a detailed study of clay minerals in the soils of the Central Plain is needed to added to the knowledge already gained about their management. Except for what has been reported by Blockuis et al. (6) that the clays belong to a transitional montmorillonite-illite series very little work has been done in this field. The presence of illite in appreciable amounts is even questionable in some Gezira and Kenana soils since some work during this study has revealed that kaolinite is more important. In the Central Clay Plain as a whole it seems that at least four different clay minerals, in variable amounts, compose the major part of the clay fraction. These are montmorillonite, kaolinite, vermiculite and illite with montmorillonite dominant. It will be shown later, as would be expected, that quartz is also present in both the coarse and fine clay fractions. Other minerals common to soils may also be present.

One important point that needs discussion and warrants further research is the occurrence of kaolinite under conditions of alkalinity and poor drainage. It was almost established that kaolinite is synthesized under conditions of acidity and good drainage. Good drainage means high permeability of the soil, steep slopes and high relief of the land. Under these conditions Ca, Mg, Na, K and Fe are removed and H ions are supplied by acids or from dissociation of water (12). Some workers (40) restricted the formation of kaolinite to low pH of 4.5 or 2.5. A pH lower than 7 however was found optimum (40). The presence of kaolinite signifies also a relatively high ratio of AL with respect to Si which may arise either from the composition of the parent rock or from removal of silicon from the environment with subsequent enrichment of AL (24).

Factors affecting kaolinization as previously cited are remarkably absent in the Central Clay Plain of the Sudan. On the contrary the present conditions contrast with these under which kaolinite is developed. For this reason it will not be difficult to account for the formation of montmorillonite which is the main mineral in these deposits. Montmorillonite is formed under conditions where an abundance of Mg, Ca, K, Na an Fe are present with low concentration of H ions and poor drainage. In fact, the parent material and land-relief are just as important as other factors such as climate, vegetation and time for the formation of clay minerals. The interplay of all these factors governs the product obtained. The presence of kaolinite is not easy to explain and large amounts of research work may be necessary before a satisfactory explanation is obtained. The presence of mica though not identified in the two soils used for this investigation is not unexpected in some other associated soils. Illite can be formed under conditions similar to those under which montmorillonite is formed if K is the alkali metal and if it is present in concentration above a certain level (21). Many investigations (21) have shown that transformation of illite from montmorillonite is possible when all exchange positions are occupied by K and the material is dried at about 110° C. The illite like material thus obtained does not again expand, even on treatment with a polar organic liquid, and it has substantially the same x-ray diffraction characteristics as illite.

The presence of chlorite as reported by Blockhuis et al. (6) in these soils is possible since some experiments by Caillere and Henin (11) have shown that chlorite can be formed from montmorillonite when the latter is treated with a solution containing Mg, so that all the exchange positions are occupied by the Mg ions. Conditions similar to those under which chlorite and illite are formed are possible to occur in the Central Plain of the Sudan.

Morphology and Classification

It was a general trend among soil technologists working in the Sudan to describe the Gezira profile according to depth and regardless of genetic horizons. This is because the genesis of this soil was and continues to be a matter of controversey. Fink (15) was the first to face the challenge and described the Gezira profile as one composed of AC horizons. Following is his description and horizon designation:

A_{11}-A_{14} horizon. 0-60-90 cm., dark brown clay /10 YR 3/3 dry, 10 YR 3/3.5 moist (in parts of the area this horizon is very dark greyish brown = 10 YR 3/2 dry)/; structure, angular blocky; consistence, very sticky and plastic, friable, hard; frequent dark grey carbonate nodules of 1-5 mm. diameter; sparse accumulation of fine white flecks of carbonate in 40-60 cm. layer; at surface friable flaky crust of few mm. (especially after rains).

A_{15}-A_{16} horizon. 60-90-120/130 cm., dark greyish brown clay (10 YR 4/1.5 dry and moist); network of tongues from upper layer decreasing with depth; structure, fine angular blocky; consistence, very sticky and plastic, firm, very hard; fine horizontal lamination, already in A_{14}; grey carbonate nodules as above; few white soft carbonate concretions (1-2 cm.) at bottom of this layer; gypsum crystals in nests (3-5 mm.); salts.

C horizon. 120-130-250 cm., brown to yellowish brown clay (10 YR 5/3-5/4 dry and moist); upper part possibly transitional A/C horizon; structure, weakly developed fine angular blocky; consistence, very hard all the year round; frequent soft and hard white carbonate concretions; gypsum lenses down to 220 cm.; salts.

It seems from his description that he considered the gray sub-soil as a continuation of the brown surface layer which he designated as an A horizon. This approach of describing vertisols as those with AC horizons was adopted by most American scientists concerned with this order. It originated from the concept that swelling of these soils combined with the self-swallowing process, that goes on when soil fragments drop from the surface into the deep cracks, seem to prevent much in the way of horizon differentiation. The vertisols were described by Smith (22) as unable under their environment to develop horizons other than a dark epipedon of variable thicknesses and sometimes a Ca horizon. In the Sudanese soils this churning process might not be severe enough to prevent horizons development and the designation of the gray layer as a B horizon is not impossible.

From some chemical and physical similarities between the Gezira soil and Houston Black Clay and the Regurs of India, Fink (15) made the following attempt to fit the soil into the American System of Classification, 7th Approximation, which is presently followed in the classification of the Sudanese soils.

Order . . . . Vertisol

Sub-Order . . . . Ustert

Great Group . . . . Grumusterts

Sub-Group . . . . Orthic Grumusterts

As stated before this order has been drastically changed and the new classification was based and centered round the cracking pattern of the soil. In the old classification usterts are defined as soils that have chromas of more than 1.5 throughout the upper 30 cm and that lack distinct or prominent mottling within the surface 75 cm (42). The new definition is that usterts are soils that have cracks that remain open for 90 cummulative days or more during the year but not throughout the year in most years and one or more of the following: (1) Cracks that open and close once during the year in most years; (2) a mean annual soil temperature of 22^{o} C. (72^{o} F.) or more; (3) a mean summer and mean winter soil temperature at 50 cm (20 inches) depth that differ by less than 5^{o} C. (9^{o} F.) (42). Despite these changes the soils of the Central Plain fit very well in this suborder. At the lower categories, the great group chromustert substituted the old group grumustert. Chromusterts are defined now as soils that have moist chroma of 1.5 or more throughout the upper 30 cm in more than half of each pedon (42). With little rearrangement the classification of the Sudanese soil can be easily modified to acquire these new terms.

CHAPTER III

LABORATORY METHODS AND PROCEDURES

Clod samples were collected from each profile, coated with saran resin in the field and shipped to the United States of America by the Soil Survey Division of the Department of Agriculture, Sudan. In the laboratory one clod was cleaned from the coating material, ground, dried and screened to pass a 2 mm sieve then retained for analyses. Other clods were used in their natural condition for the determination of bulk density, porosity, available moisture and coefficient of linear extensibility (COLE). Fifty gram samples were used for particle size distribution according to a procedure described by Jackson (25). The sand fraction was separated into the five standard fractions by sieving. The clay was further fractionated into coarse clay (2, 0.2μ) and fine clay (< 0.2μ) using a superspeed centrifuge. The x-ray diffraction analysis was made on the coarse and fine clay fractions according to the Jackson method (25). Total K_2O was determined in each clay fraction by digesting 0.1 gm sample with HF (26). The methods of Jacobs and Morin (36) and Bower and Gschwend (8) were used for the determination of surface area. The relations given by Jackson (25) were used to calculate planar area. CEC was determined by the calcium saturation and EDTA titration as described by Jackson (26). Saran resin was used to coat natural clods for bulk density and water retention measurement according to the recent method of Brasher, Franzmeier and Valassis (10).

The method of Kiely and Jackson (30) was used to determine feldspar and quartz. Sodium pyrosulphate rather than $K_2S_2O_7$ was used in this determination. The latter was found to result in some replacement of sodium and calcium by potassium in the plagioclose feldspars. E. C., ph, CEC, exchangeable cations and soluble anions were determined in the total soil according to the methods described in the U.S.D.A. Handbook 60 (44). Calcium carbonate determinations were made using Collin's calcimeter. The modified Walkely, Black (26) method was used in the determination of organic carbon. Extractable or free iron was determined by the method of Holmgren (23).

CHAPTER IV

RESULTS AND DISCUSSION

Descriptions of the Sampled Soil Profiles

Location: Central Gezira, Tebub Block, Pit B

Native Vegetation: *Savana*, *Acacia* shrubs and short grass. Presently the land is under cotton cultivation.

Parent material: Pleistocene clay deposits from basaltic source.

Topography: Flat, level alluvial plain.

Surface: Granular mulch, regular pattern of cracks enclosing units of 75 cm in diam. Width of cracks 4 cm, depth 100 cm.

Soil Profile:

Depth cm	
0 - 2	Dark grayish brown (10YR4/2) clay loose granular mulch, pH 8.2
2 - 55	Dark grayish brown (10YR4/2 dry) clay; platy to subangular blocky; dry, hard, $CaCO_3$ nodules, shell fragments, common fine roots, sand pockets few medium and thick roots, with slickface, $CaCO_3$ patches, pH 8.3, gradual boundary to:
55 - 80	Very dark grayish brown (10YR3/2 dry) to dark brown (10YR3/3 moist) clay weak subangular blocky with platy components, dry, hard, black $CaCO_3$ nodules, sandpockets, few shell fragments, pH 8.4, gradual boundary to:
80 - 110	Very dark gray (10YR3/1 dry) to dark yellowish brown (10YR3/5 moist) clay, subangular blocky to massive, slightly moist, friable, fine gypsum $CaCO_3$ flecks, few thin roots; slickensides, termite holes, few mottlings, pH 7.9, gradual

boundary to:

110 - 140	Very dark gray (10YR3/1 dry) dark brown (10YR3/3) moist, clay, weak subangular blocky to massive, massive, slightly moist, friable few fine gypsum, Mn coatings, few thin roots $CaCO_3$ flecks, pH 9.0, Gradual boundary to:
140 - 155	Very dark gray (10YR3/1 dry) very dark grayish brown (10YR3/2 moist) clay; slightly moist, friable, distinct mottling big patches of $CaCO_3$ fine and medium gypsum, pH 8.1, clear boundary to:
155 - 190	Very dark grayish brown ((10YR3/2) clay; subangular blocky, slightly moist, friable, fine + coarse gypsum, few $CaCO_3$ nodules, mottlings, Mn coatings pH 8.0

Location: Pit KP03, Kenana

Native Vegetation: Savana; *Acacia* trees and tall grass. Land is now cotton irrigated.

Parent material: Probably pleistocene clay deposits from basaltic sources.

Topography: Flat, level plain.

Surface: Granular mulch about 2 cm thick, few cracks.

Soil Profile:

Depth cm.	
0 - 2	Surface mulch 2 cm thick, well developed.
2 - 20	Very dark grayish brown (10YR3/2) clay; moderate medium subangular blocky structure; friable to firm; few fine roots; cracks 2 cm wide, common fine and medium $CaCO_3$ concretions; pH; boundary clear and irregular to:
20 - 60	Very dark grayish brown (10YR3/2) clay; weak medium angular blocky structure; firm; common fine and medium roots; common fine white $CaCO_3$ concretions; few black concretions; few sand pockets; few clay balls, slickensides are prominent; pH 8; diffuse boundary to:
60 - 100	Same as above

100 - 120	Very dark grayish-brown (10YR3/2) clay; massive; very firm; common fine and medium roots; few fine $CaCO_3$ concretions; slickensides clear; pH 8.5; diffuse boundary to:
120 - 160	Very dark gray (10YR3/1) clay; massive, very firm; few fine roots; common medium $CaCO_3$ concretions increasing with depth; common soft mycelium calcium; slickensides; pH 8.5; diffuse boundary to:
160 - 200	Same as above. Substratum is massive clay.

Particle Size Distribution

The results of the particle size distribution analysis for both locations of Unit 13 is given in Table V and VI and in Appendix Tables XVII and XIV. The data indicate the following points: (1) Considering the whole profile the clay content represents 62 percent, silt 17 percent and sand 17 percent of the total soil in Kenana on carbonate free bases. In the Gezira the clay represents 56 percent, silt 18 percent and sand 21 percent of the total soil. (2) While the total clay remains almost constant with depth in Kenana soil, and shows very little increase in the Gezira, the fine clay increases progressively with depth until reaching a maximum between 65 - 125 cm in the Kenana and 50 - 115 cm in the Gezira. This maximum indicates 41 percent increase in the fine clay with respect to the content of the surface horizon in Kenana soil and 76% increase in the Gezira soil. (3) From the steady increase of the fine clay in both profiles and its decrease at the C horizon it may be concluded that part of this clay has been illuviated down the profile by the same forces, mainly water rather than being formed in the sub-soil. Nevertheless, it is not enough clay increase to characterize an argillic horizon. (4) The higher clay content of Kenana soil is probably due to depositional processes rather than to soil

TABLE V

PARTICLE SIZE DISTRIBUTION OF UNIT 13 - GEZIRA*

Depth cm	V.C.S.	C.S.	M.S.	F.S.	V.F.S.	Total Sand	Silt	Total Clay	Fine Clay
0-20	5.3	3.7	3.7	5.4	5.7	23.8	21.5	52.0	17.3
20-50	5.4	4.3	3.7	5.9	6.0	25.3	13.3	57.2	22.9
50-115	4.9	3.1	3.1	4.9	5.6	21.4	17.8	56.0	30.3
115-155	2.7	1.5	1.7	3.5	3.2	12.6	20.5	58.5	17.6

*Values in percent

TABLE VI

PARTICLE SIZE DISTRIBUTION OF UNIT 13 - KENANA*

Depth cm	V.C.S.	C.S.	M.S.	F.S.	V.F.S.	Total Sand	Silt	Total Clay	Fine Clay
5-35	1.9	2.5	1.9	5.9	4.4	16.6	18.1	61.1	21.9
35-65	1.3	2.1	1.9	6.1	5.6	17.0	14.5	61.1	27.7
65-125	2.0	2.0	1.8	5.4	4.8	16.0	17.0	63.3	30.8
125-180	2.6	1.6	1.5	4.7	4.3	14.7	17.9	64.1	26.8

*Values in percent

forming processes otherwise the latter would have left the profile with more definite textural horizons. However, in Vertisols this is not always the case. The churning process may prevent the formation of textured horizons and it would not be possible to recognize whether a certain characteristic of a soil is due to soil forming factors or inherited from the parent material. The same difficulty is encountered in comparing the stages of soil formation in the Gezira and Kenana profiles. Though the Gezira has much more illuviation than Kenana it is not certain to claim a more advanced stage of soil development unless the soil mixing process was not severe enough to destory imprints left from the profile development processes. In fact, the self-swollowing process in the Sudanese Vertisols is not as active as in similar soils in the United States and other parts of the world as has been noticed by some visiting American soil scientists.[1] It may be presumed therefore that where churning tends to break up the profile some other soil forming factors tend to restore it. The latter being more effective. More discussion will be given under the genesis of these soils.

Clay Mineralogy

Four methods were used in studying the coarse clay and fine clay fractions of both soils. These methods were x-ray diffraction, cation exchange capacity, determination of external and internal surface area and determination of the total K_2O content. The data obtained from the latter three methods are presented in Table VII and VIII. The x-ray analyses were done in three selected depths from each profile and the diffractograms are shown in Figures 4, 5, 6, and 7.

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[1]Rahad Pre-Appraisal Mission Report. Personal communication.

TABLE VII

SELECTED CHEMICAL AND PHYSICAL DATA ON THE CLAY FRACTION OF UNIT 13 - GEZIRA

Depth cm	% K_2O	CEC meq/100 gm	Surface Area, m^2/gm Total	External	Internal	Planar	% M+V	% K+Q	%[+] I
				Coarse Clay					
0 - 20	0.90	74.5	496	174	322	467	58	37 ± 5	5 ± 4
20 - 50	0.72	85.5	648	198	450	615	76	20 ± 4	4 ± 3
50 - 115	0.85	74.5	536	130	406	514	64	32 ± 4	4 ± 4
115 - 155	0.79	88.2	583	235	348	544	62	58 ± 4	4 ± 3
				Fine Clay					
0 - 20	0.54	96.5	836	413	423	767	95	3 ± 2	3 ± 2
20 - 50	0.66	102.0	810	377	433	747	92	4 ± 4	3 ± 3
50 - 115	0.59	104.8	826	386	440	762	94	3 ± 3	3 ± 2
115 - 155	0.54	102.0	832	366	466	770	95	3 ± 2	3 ± 2

[+] M = montmorillonite, V = vermiculite, K = kaolinite, I = illite, Q = quartz

TABLE VIII

SELECTED CHEMICAL AND PHYSICAL DATA ON THE CLAY FRACTION OF UNIT 13 - KENANA

Depth cm	% K_2O	CEC meq/100 gm	Surface Area, m^2/gm				% M+V	% K+Q	%[+] I
			Total	External	Internal	Planar			
			Coarse Clay						
5 - 35	0.69	82.7	571	243	328	530	66	31 $\pm$ 3	3 $\pm$ 3
35 - 65	0.64	85.5	556	243	313	516	64	33 $\pm$ 3	3 $\pm$ 3
65 - 125	0.66	74.5	502	238	264	462	57	41 $\pm$ 3	3 $\pm$ 3
125 - 180	0.62	88.2	523	273	250	478	59	38 $\pm$ 3	3 $\pm$ 3
			Fine Clay						
5 - 35	0.42	113.1	765	360	405	705	87	11 $\pm$ 2	2 $\pm$ 2
35 - 65	0.59	107.5	771	360	411	711	88	9 $\pm$ 3	3 $\pm$ 2
65 - 125	0.40	115.8	819	403	416	754	93	5 $\pm$ 2	2 $\pm$ 2
125 - 180	0.43	99.3	865	305	560	814	115*	*	2 $\pm$ 2

*Probably error in the surface area determination.
[+]M = montmorillonite, V = vermiculite, K = kaolinite, I = illite, Q = quartz

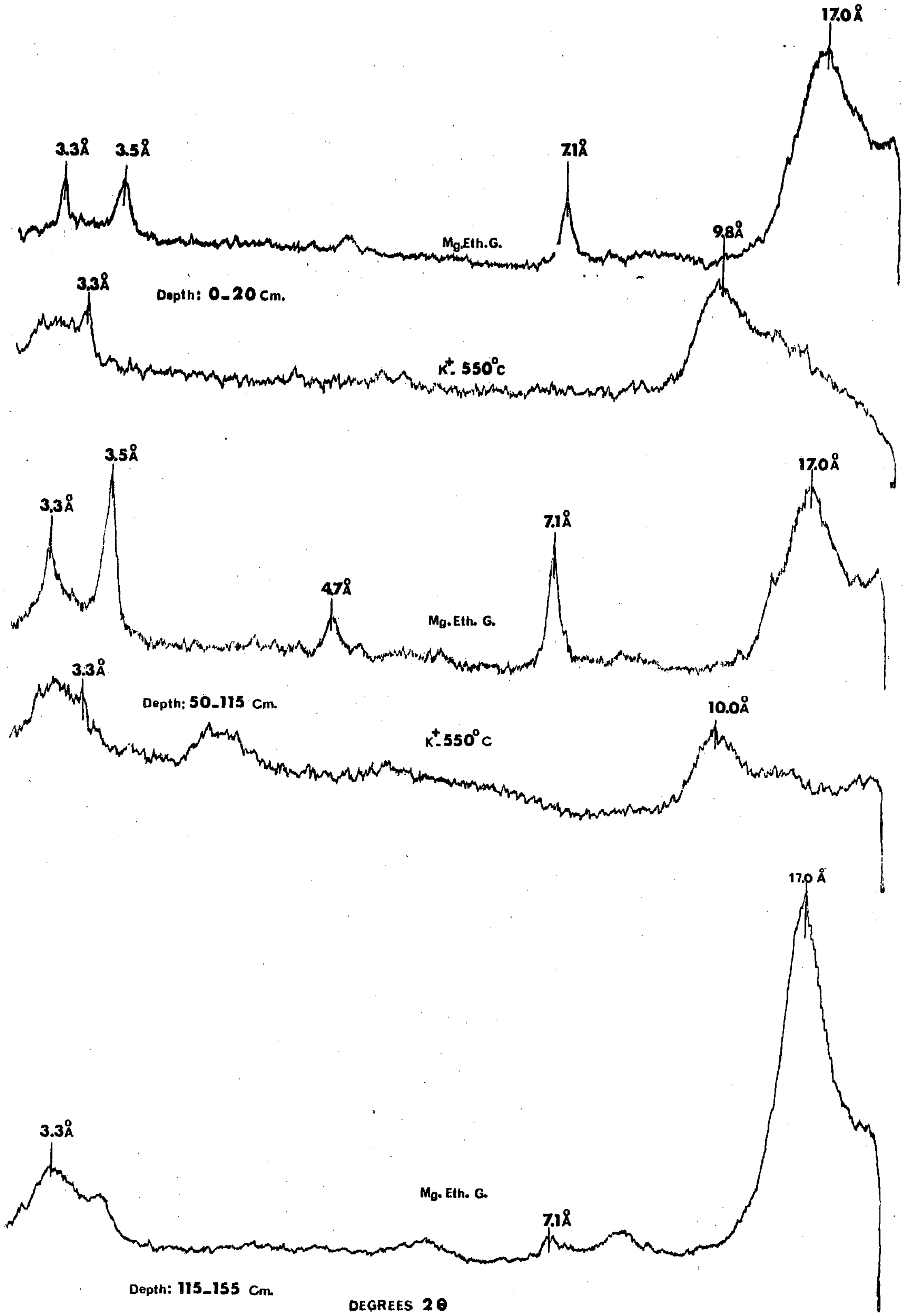

Figure 4. X-ray Diffractograms of Coarse Clay Samples from Three Horizons of the Gezira Soil.

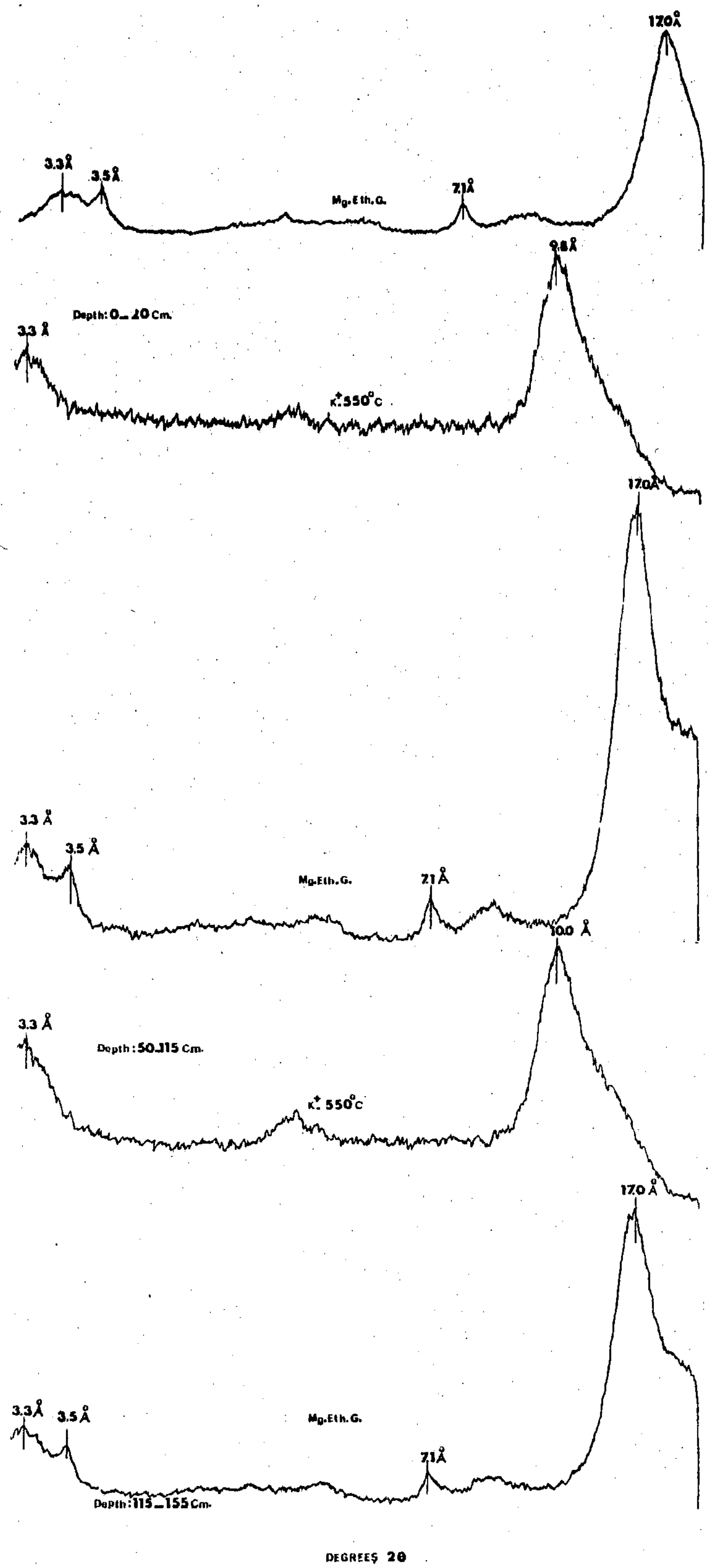

Figure 5. X-ray Diffractograms of Fine Clay Samples from Three Horizons of the Gezira Soil.

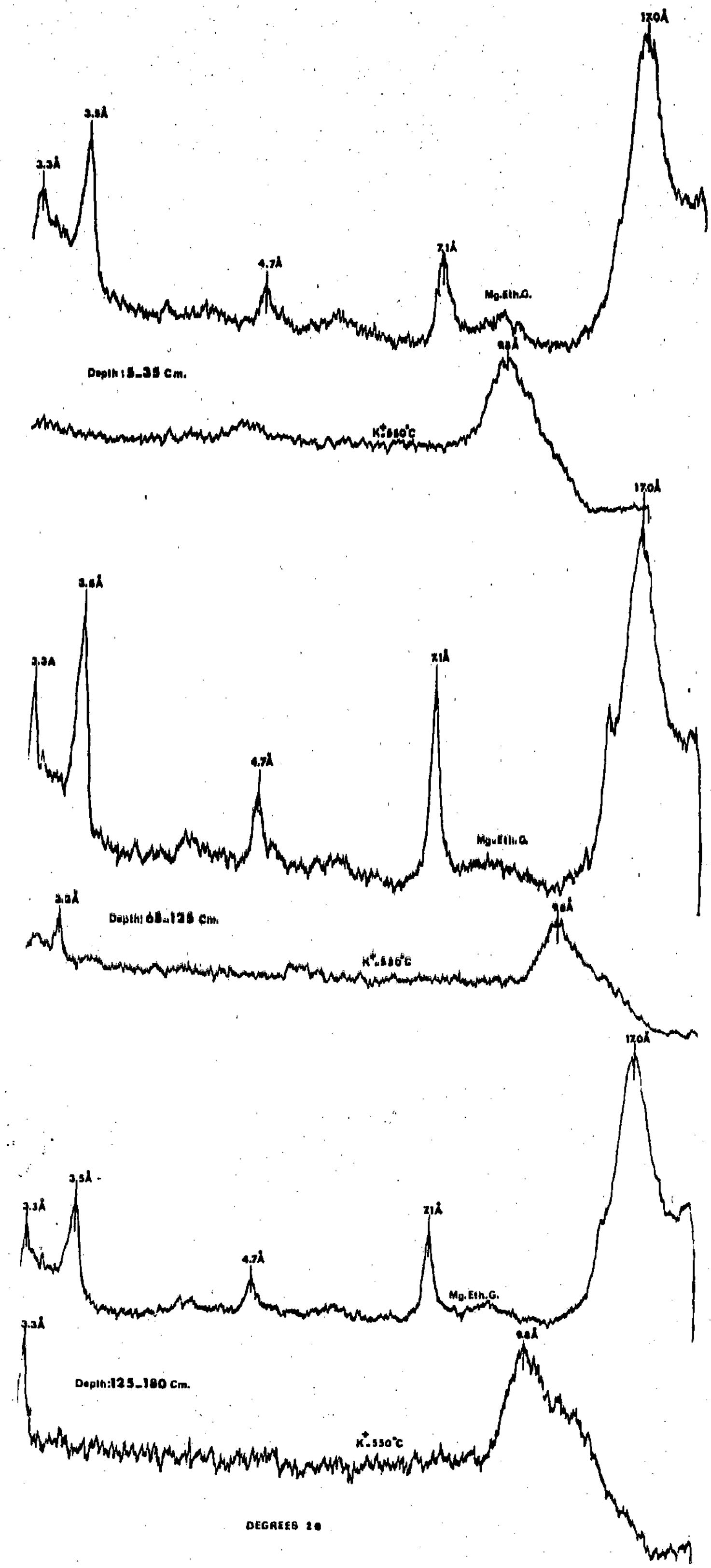

Figure 6. X-ray Diffractograms of Coarse Clay Samples from Three Horizons of the Kenana Soil.

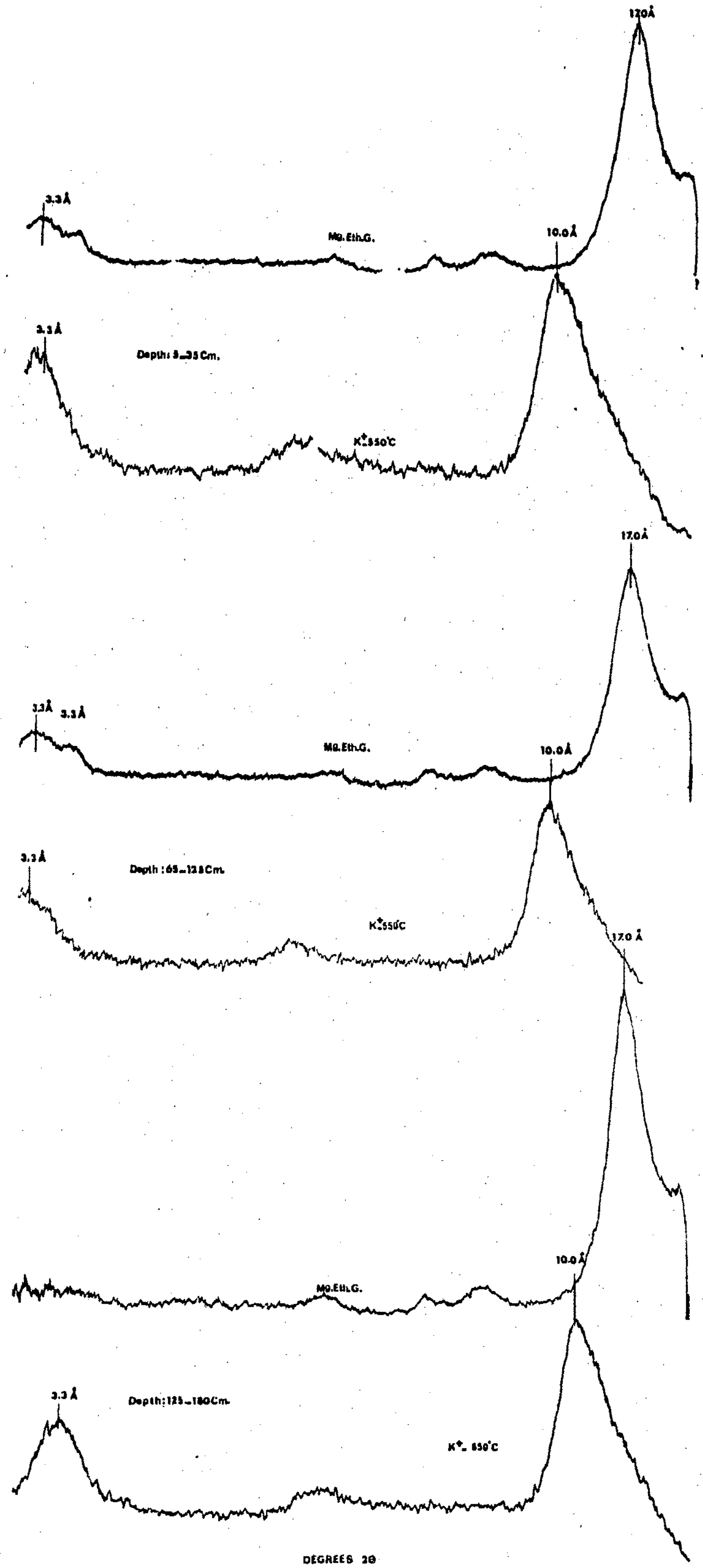

Figure 7. X-ray Diffractograms of Fine Clay Samples From Three Horizons of the Kenana Soil.

Total K_2O

The objective of the K_2O determination was to estimate the amount of illitic mica minerals in both the fine and coarse clay fractions of the two soils. Grim (21) suggested a 11.8% K_2O value to represent 100% illite. This value was modified by Mehra and Jackson (34) who established a value of 10% K_2O. The content of K_2O in the coarse clay ranges from 0.8 - 0.9% in the Gezira soil to 0.7 - 0.6 in Kenana. In the fine clay it is 0.5 - 0.7 in the Gezira and from 0.4 - 0.6 in the Kenana. From these values it is clear that micaceous potassium mica minerals are not important in these deposits. In fact illite is present in such small amounts that it did not show in the x-ray diffractograms. Nevertheless its amount can be estimated using the total K_2O procedure. This value on the other hand is not a point of general agreement, yet considered by many as a good indication of the amount of illite. Considering the whole profile and using the value of Mehra and Jackson (34) the results of this investigation indicated that illite represents between 8 to 9% in the coarse clay and 5 to 7% in the fine clay of the Gezira soil. In Kenana it makes up about 6 to 7% of the coarse clay and 4 to 6% of the fine clay. It may even be less than the values shown above because a small correction should be made for the K present in feldspars. Such correction was not found feasible for this study. The illite content of the soil seems to be consistent with depth in the two sampled profiles.

Cation Exchange Capacity and Surface Area Determinations

Both determinations were made to estimate montmorillonite in the clay fraction of the two soils. The CEC of the coarse clay ranges between 83 to 88 meq/100 gm in the Gezira soil and 74 to 88 meq/100 gm in Kenana. The fine clay has a CEC of 100 to 113 meq/100 gm in the Kenana soil and 97 to 105 meq/100 gm in the Gezira. The results obtained from surface area determinations were less consistent than the other data obtained from the other methods used for characterization of the clay minerals. The planar surface area of the coarse clay fraction of the Gezira soil varies between 467 and 615 m^2/gm.

The fine clay fraction of the same soil gave a value of 747 to 770 m^2/gm. In Kenana the coarse clay has a planar surface area of 462 to 530 m^2/gm and from the fine clay a values of 705 to 814 were obtained. The planar surface area was calculated according to a relation given by Jackson (25) as follows:

$$\text{Specific Planar Surface, } m^2/gm = \text{Specific Interlayer Surface} + \frac{5}{6} \times \text{External Surface}$$

This value was used to estimate montmorillonite + vermiculite according to the equation of Mehra and Jackson (34)

$$\% \text{ (Montmorillonite + Vermiculite} = \frac{(\text{Planar surface, } m^2/gm)(100)}{808 \ m^2/gm}$$

Since the x-ray results indicated the presence of vermiculite in the coarse clay fraction of the two soils an estimate of the amount of the sum of the two minerals was only possible. However, the above relation was used to estimate the percentage of montmorillonite only in the fine clay fraction since the x-ray diffractograms have shown no vermiculite. Even in the coarse clay vermiculite is believed to be present in very small amounts compared to montmorillonite. The estimates of montmorillonite, vermiculite and illite in the coarse and fine clay fraction of the two soils are given in Table VII and VIII. The remainder of the clay fraction was assigned to kaolinite + quartz, both minerals were obviously shown on the x-ray pattern.

In the light of the ethylene glycol retention values, total K_2O and CEC determinations along with x-ray analyses it appears that a montmorillonitic type mineral dominates the clay fraction of both the Gezira and Kenana soils. The coarse clay fraction which comprises approximately 35% of the fine soil in the two profiles is composed dominantly of montmorillonite with smaller amounts of kaolinite, vermiculite probably illite and quartz. The fine clay fractions which represents about 22% of the fine earth of the Gezira soil and about 27% of Kenana is made primarily of montmorillonite with traces of finally divided quartz. The data obtained during the course of this study were not sufficient to give definite estimate of the amount of each clay mineral. However the following tentative conclusions could be made: (1) Montmorillonite plus small amounts of vermiculite comprise between 50 to 70% of the coarse clay fraction of the two soils, (2) Illite ranges between 0 and 9%, (3) Kaolinite plus small amounts of quartz 30 to 40% in the same fraction of the two soils, (4) The fine clay fraction of the two soils is composed of over 90% montmorillonite. Traces of quartz and kaolinite may be present.

X-Ray Analysis

The x-ray patterns of the coarse and fine clay fractions of the two soils at three selected depths are shown in Figures 4 - 7. The conclusions drawn before about the clay mineralogy of these soils were to some degree supported by the following interpretation of the x-ray diffractograms. The 17A^{o} peak in the diffractograms of the Mg saturated, ethylene glycole solvated samples and the closure of this peak to 10A^{o} when the clays were saturated with K and heated to 550^{o} C. was taken as an indication of montmorillonite. The broadening peak of montmorillonite in some patterns may indicate that this mineral is probably interstratified with vermiculite. The presence of vermiculite was also obvious from the 14A° peak which was destroyed by heating the sample to 550° C. It was also confirmed by the low intensity reflection of the 3rd order peak at 4.7A°. The 7.1A° peak which disappeared after heating a K saturated sample to 550° C., and the 3.5A° peak which has more or less the same intensity of the reflection at 7.1A° were found adequate to identify the 1st and 2nd order reflection of kaolinite. The reflection of 3.3A° is most probably due to quartz which is almost present in any soil in varying amounts. Unexpectedly, a reflection of 10A° or 5A° which characterizes illite was remarkably absent in the x-ray diffractograms of all samples. This is not in agreement with the claim of Blockhuis, Ochtman and Peters (6). The presence of vermiculite rather than chlorite and its stratification with montmorillonite as found during this study was also not in accord with their description of these clays. That illite is present only as traces was also confirmed by the very small amount of total K_2O content of the two clay fractions as stated before.

Physical Properties

The results of some selected physical properties of the Gezira and Kenana soils are given in Table IX. These include bulk density, available moisture, porosity and coefficient of linear extensibility (COLE). The data indicated that the Gezira soil has a bulk density of 1.57 at the surface horizon increasing progressively until it reaches a maximum of 1.89 at a depth of 75, 115 cm. The same trend was observed in Kenana soil which has a bulk density of 1.80 at the surface horizon increasing steadily to 1.98 at a depth of 25, 150 cm. Both soils showed a

TABLE IX

BULK DENSITY, POROSITY, AVAILABLE MOISTURE AND COEFFICIENT OF LINEAR EXTENSIBILITY OF UNIT 13

Depth cm	Db 1/3 bar* gm. cm^{-3}	Db od* gm. cm^{-3}	H_2O at 1/3 bar	% Available Moisture	% Porosity	COLE*
			Gezira			
0-20	1.28	1.57	29.2	37.4	51.6	0.0705
20-50	1.28	1.72	33.6	43.0	51.6	0.1035
50-75	1.29	1.84	33.4	43.0	51.2	0.1257
75-115	1.29	1.89	33.2	43.0	51.2	0.1358
115-155	1.20	1.80	38.4	46.0	54.8	0.1448
			Kenana			
5-35	1.24	1.80	36.7	45.5	53.3	0.1323
35-65	1.20	1.93	40.1	48.1	54.8	1.1716
65-125	1.21	1.98	38.4	45.3	54.4	0.1784
125-150	1.20	1.94	41.1	48.1	54.8	0.1696
150-180	1.11	1.82	46.2	51.2	58.2	0.1792

*Db 1/3 bar = bulk density at 1/3 bar
Db od = bulk density at oven dryness
COLE = Coefficient of linear extensibility

decrease in bulk density at the C horizon. This investigation clearly suggests that the Kenana profile is more compacted than the Gezira profile and that both soils are so dense that some difficulty in their management can be anticipated. It has been shown that when the bulk density of medium to fine textured subsoil exceeds about 1.7 gm. cm^{-3} hydraulic conductivity values will be so low that drainage problems can be expected (44). In these soils internal drainage is very poor and water moves mainly through the cracks which are more effective than infiltration rate in conveying water to the deep horizons. Under this highly compacted condition of the soil profile the stunted growth of some cotton plants, as observed in this plain, may probably be due to the adverse physical condition of the soil. The increase in bulk density with depth in both soils may be due partly to illuviation of the fine clay fraction. These fine particles moving down the profile with the percolating water are dispersed with sodium and fill the interstices of the soil matrix creating a more dense layer in the subsoil. If this is true, then deep ploughing might not be effective in loosening the subsoil and the hard layer may build up again within a short time. The validity of this statement, however, remains doubtful until tested by experimental field work. From the uniformity of the bulk density determination results it may also be concluded that the compactness of the whole profile was likely inherited from the fine clay parent material and the slightly harder subsoil was a result of the soil forming factors.

Availability of Water

Available water was estimated for each horizon of the two sampled profiles. The 1/3 bar moisture volume percentage was used as an estimate of the amount of water held at field capacity. This value was obtained by multiplying the 1/3 bar moisture weight percentage by the bulk density of a natural soil clod at 1/3 bar. Soil clods with the least possible disturbance were used, rather than sieved samples to calculate the bulk density at 1/3 bar and to estimate the moisture weight percentage at the same tension. The use of natural soil clods has been recommended by many researchers (31, 14, 3, 33) because it has been found that the water content at field capacity is overestimated if sieved soil samples were used to obtain the 1/3 bar desorption value. Young and Dixon (46) compared the 1/3 bar moisture volume percentage which is often used as an estimate of the amount of water held at field capacity with the porosity of the soil and they found that impossible values were sometimes obtained. They presented some data which showed that the volume of water held by a soil at 1/3 bar as estimated from a sieved sample was greater than the volume of total pore space of the soil in its natural condition, which is impossible. The results obtained from this study indicated that the Gezira soil has a slightly lower capacity to hold water at field range than the Kenana soil. In the Gezira available water increases from 37% in the surface horizon to 43% in the subsoil and to 46% in the C horizon. Values of 45% in the surface horizon which increased to 51% in the C horizon of the Kenana profile were obtained. The results were checked with the pore space of the soil in its natural condition. Porosity was calculated according to the following relation:

$$\text{Porosity} = \frac{(Dp - Db1/3bar) \times 100}{Dp}$$

Where Dp is the assumed particle density of 2.65 and Db1/3 bar is the bulk density at 1/3 bar. The data indicated that the water content of each horizon in both profiles was reasonably exceeded by the total pore space of the soil in its natural structural condition.

Despite how reliable and consistent these data; available water can best be determined under representative field conditions, because in addition to its dependence upon texture it also depends on the variation throughout the profile of such factors as water conductivity and pore size distribution. In the Central Clay Plain of the Sudan water conductivity is low and the high water holding capacity shown in Table IX does not always indicate sufficient water to support plant growth.

Coefficient of Linear Extensibility (COLE)

One of the important characteristics of vertisols is their high coefficient of expansion and contraction on wetting and drying. This coefficient is defined as the ratio of the difference between the moist and dry lengths of a clod to its dry length and is described by the following equation:

$$\mathrm{COLE} = \frac{Lm - Ld}{Ld}$$

Where Lm and Ld are the moist and dry lengths of the clod respectively (42). It is usually calculated from the difference in bulk density of the clod when moist and dry according to this relation:

$$\mathrm{COLE} = \left(\frac{Dbd}{Dbm}\right)^{\frac{1}{3}} - \frac{1}{1}$$

Where Dbd and Dbm are the bulk densities at the dry and moist conditions. The values obtained from the Gezira and Kenana soils are shown in Table IX. As might be expected the Kenana has a greater capacity of expansion

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[1] Private communication with Mr. B. R. Brasher, Soil Scientist at the Salinity Laboratory (USDA), Riverside, California.

than the Gezira because of its higher montmorillonitic minerals content and higher ESP assuming that other clay minerals are more or less the same in the two soils. The COLE increases steadily from 0.0705 in the surface horizon of the Gezira soil to 0.1448 in the lower part of the profile. In Kenana it increases from 0.1323 in the surface to 0.1792 in the C horizon. The advantage of using soil clods in this kind of study is that measurements of change in volume with controlled water content are possible. Such measurements are useful in determining soil shrinkage that accompanies drying in order to develop the relation that exists between soil moisture and volume change. However error is introduced if the values of expansion are used to predict the movement of the soil in its field natural condition because a clod in the laboratory undergoes volume change in the absence of soil load pressure which is not the case in the field. This is obvious from the results already obtained from a field test run in similar Gezira soil. It has been found that the upward movement of the soil in wetting decreases with depth from 12.5 cm in the surface to zero cm at a depth of about 180 cm.

The peculiar relation between the cotton yield and clay percentage (high clay percentage is associated with high cotton yield) observed in these fine clay soils of the Plain could be explained in the light of swelling-shrinkage phenomenon. In these poorly drained soils water movement, as previously stated, depends mainly on cracks whose magnitude is influenced by the amount and kind of clay minerals as well as the kind of cations saturating the clay fraction. The coefficient of linear extensibility which is a measure of shrinkage that develops cracks in the soil could accordingly be tested as a criterion of land assessment.

Soil Weathering

The feldspars and quartz were determined in the very fine sand (50-100μ) and silt (2-50μ) fraction of all horizons of the two profiles in order to gain some information about soil weathering. The results obtained from the silt fraction may not be as reliable as the results obtained from the very fine sand fraction, because the whole silt (2-50μ) was used for analysis rather than one of the silt fraction (2-50μ, 5-20μ, 20-50μ) as recommended by Kiely and Jackson (30), on the bases that mineral species tend to concentrate within a limited particle size. However Graham (17) used the whole silt fraction of several soils and standard feldspar minerals as a check to determine an index of soil weathering. The results obtained from this study are shown on Tables X and XI. The data indicated that Kenana soil has more feldspars and less quartz than the Gezira soil. The percentage of total feldspars is about 17% in the very fine sand fraction of the Gezira soil and approximately 37% in the same fraction of Kenana soil. In the silt fraction feldspars represent about 37% in the Gezira and about 40% in Kenana. The Na member dominates the feldspars minerals in the silt and sand fractions of all horizons of the two soils. In the very fine sand quartz represents about 83% in the Gezira and 72% in Kenana. In the silt fraction it constitutes about 63% in the Gezira and 60% in the Kenana. The quartz content of the two profiles follows the same trend of showing very little variation with depth.

From the feldspar data, it would appear that the soils of Unit 13 as represented by the two sites of this investigation are moderately weathered. Their feldspar minerals are dominated by the intermediate members labradorite, andesite and oligoclase. These minerals release

TABLE X

THE PERCENTAGE OF NA, CA AND K FELDSPARS AND THE QUARTZ-FELDSPARS RATIO IN THE V.F. SAND AND SILT FRACTIONS OF UNIT 13 - GEZIRA

Depth cm	% K Feldspars	% Na Feldspars	% Ca Feldspars	% Total Feldspars	% Quartz	Quartz / Feldspars	Na_2O / CaO
				V.F. Sand			
0-20	4.1	8.5	2.8	15.4	84.6	5.5	1.75
20-50	4.8	8.4	5.4	18.6	81.4	4.4	0.90
50-75	4.8	8.4	5.4	18.6	81.4	4.4	0.90
75-115	4.8	8.5	3.9	17.2	82.8	4.8	1.28
115-155	4.4	9.4	3.1	16.9	83.1	4.9	1.75
				Silt			
0-20	7.1	22.1	12.4	41.6	58.4	1.4	1.04
20-50	7.1	22.1	8.4	37.6	62.4	1.7	1.53
50-115	7.1	22.1	8.4	37.6	62.4	1.7	1.53
115-155	5.9	23.0	4.7	33.6	66.4	2.0	2.84

TABLE XI

THE PERCENTAGE OF NA, CA AND K FELDSPARS AND THE QUARTZ-FELDSPARS RATIO IN THE V.F. SAND AND SILT FRACTIONS OF UNIT 13 - KENANA

Depth cm	% K Feldspars	% Na Feldspars	% Ca Feldspars	% Total Feldspars	% Quartz	$\frac{\text{Quartz}}{\text{Feldspars}}$	$\frac{Na_2O}{CaO}$
				V. F. Sand			
5-35	7.7	16.2	5.0	28.9	71.1	2.5	1.90
35-65	7.1	16.2	5.0	28.3	71.7	2.5	1.90
65-125	7.1	16.2	4.9	28.2	71.8	2.5	1.92
125-150	6.5	16.2	5.4	28.1	71.9	2.6	1.73
150-180	6.5	16.2	4.9	27.6	72.4	2.6	1.73
				Silt			
5-35	7.7	23.8	10.9	42.4	57.6	1.4	1.27
35-65	8.9	25.5	9.9	44.3	55.7	1.3	1.50
65-125	8.3	26.4	2.2	36.9	63.1	1.7	6.9
125-180	7.7	26.4	2.0	36.1	63.9	1.8	7.6

significant amounts of both calcium and sodium in the soil during weathering. Assuming both soils have approximately the same parent material, which is most probably the case, then it could be concluded that the Gezira soil was more weathered than Kenana soil. This conclusion was based on the lower quartz/feldspars ratio of Kenana soil. Considering the NaO_2/CaO ratio it would appear that the gray sub-soil in the two profiles is more weathered than the surface soil. This may again justify the description of the gray subsoil as a cambic horizon.

Chemical Properties

Selected chemical properties of these soils are presented in Tables XII - XV and Appendix Tables XVII-XIX. As would be expected in these calcareous soils the pH is alkaline throughout the depth of the sampled profile. It is about 8 or more in all horizons. In a KCl solution it was found to be approximately 1.4 units lower than that obtained by mixing the soil with water. By increasing the soil water ratio to 1:5 higher values were obtained than those measured on a paste (approximately 1:1). This variation could be attributed to the effect of different concentrations of salts in the double layer. With high salt concentration the double layer becomes more compact and the pH in the solution approaches that pH found on the surface of the soil particles which is usually lower than the pH of the soil solution.

Calcium carbonate occurs in all horizons of the two profiles in variable amounts. It is apparent that the Gezira soil has a higher percentage of $CaCO_3$ than the Kenana. The results obtained were erratic and statements about leaching and relation of the carbonate to the parent material were not possible.

The electrical conductivity of the saturation extract as a measure

TABLE XII

SELECTED CHEMICAL PROPERTIES OF A SOIL FROM CENTRAL GEZIRA, SULEIMI BLOCK

Depth cm	Soluble cation and anions in meq/litre Saturation Extract						SSP*	TSC*
	Na	Ca	Mg	Cl	HCO_3	CO_3		
SM	3.0	4.0	1.0	2.0	4.2	0.0	37.5	8.0
0-45	3.0	0.5	0.3	1.0	2.5	0.0	80.0	3.8
45-60	4.0	3.0	2.0	2.0	2.2	0.5	44.5	9
60-85	4.0	1.0	1.0	0.6	2.4	0.7	66.7	6
85-140	6.0	1.5	1.5	0.6	2.8	0.7	66.7	9
140-175	27.0	9.0	3.5	1.5	2.3	0.0	68.5	39.5
175-200	44.0	22.0	11.0	1.0	1.9	0.0	57.0	77.0

*SSP = Soluble Sodium Percentage
TSC = Total Soluble Cations

TABLE XIII

CHEMICAL ANALYSIS OF KENANA SOIL - UNIT 13

Depth cm	pH Paste	pH 1:5	E.C. on Sat. Ext. mmohs/cm	Soluble Cations and Anions in meq/L Sat. Ext. Na	Ca	Mg	Cl	HCO_3	CO_3	SSP*	TSC*
0-2	7.6	8.6	0.95	5.0	2.0	1.0	1.6	1.6	0.4	62.5	8
2-20	8.3	8.5	0.60	3.0	1.0	1.0	1.2	1.4	0.8	60.0	5
20-60	7.9	8.7	0.78	6.0	2.0	1.0	0.7	1.9	0.0	66.5	9
60-100	8.1	9.0	1.11	8.0	1.5	1.5	0.7	2.1	0.0	72.5	11
100-120	8.0	8.9	1.5	12.0	1.0	1.0	1.2	3.5	0.7	86.0	14
120-160	8.1	9.1	2.1	16.0	1.5	1.5	2.0	3.0	1.5	84.0	19
160-200	8.3	9.1	1.6	13.0	1.0	1.0	4.0	2.7	2.3	87.0	15

*SSP = Soluble Sodium Percentage
TSC = Total Soluble Cations

TABLE XIV

SELECTED CHEMICAL PROPERTIES OF A SOIL FROM CENTRAL GEZIRA TEBUB BLOCK

Depth cm	pH		$CaCO_3$ %	E.C. on Sat.Ext. mmohs/cm	C.E.C. meq/100 gm	Exch.Na meq/100 gm	Organic Matter %	ESP	Free Fe_2O_3	
	Paste	1:5							Depth cm	%
0-2	8.2	9.1	3.8	1.6	58	6.0	0.47	10.0	0-20	1.77
2-55	8.3	9.7	3.3	0.8	54	4.2	0.45	8.0	20-50	1.80
55-80	8.4	9.8	6.6	1.4	60	12.8	0.40	21.0	50-75	1.84
80-110	7.9	9.0	4.7	7.8	71	12.1	0.72	17.0	75-115	1.72
110-140	9.0	9.3	5.6	5.8	74	16.3	0.90	22.0	115-155	1.24
140-155	8.1	9.6	6.6	8.5	75	12.6	0.64	17.0		
155-190	8.0	8.3	6.4	8.3	61	15.4	0.55	25.0		

TABLE XV

SELECTED CHEMICAL PROPERTIES OF KENANA SOIL - UNIT 13

Depth cm	$CaCO_3$ %	CEC meq/100 gm	Exch.Na meq/100 gm	Organic matter %	ESP	Free FeO_3 Depth cm	Free FeO_3 %
0-2	8.5	61	5.0	1.12	5.0	5-35	2.42
2-20	2.4	63	3.0	.93	6.0	35-65	2.72
20-60	1.9	63	6.0	0.76	14.5	65-125	2.57
60-100	2.2	64	8.0	0.74	20.0	125-150	2.71
100-120	0.9	68	12.0	0.76	20.0	150-180	2.38
120-160	1.8	69	16.0	0.72	20.0		
160-180	5.0	71	13.0	0.93	21.0		

of soluble salt increases progressively from 1.6 mmohs/cm. at 25° C. at the surface horizon to 8.5 mmohs/cm. at 25° C. at a depth of 140.55 cm. in the Gezira profiles. In the Kenana soil the same trend was also observed, however, this soil is much less saline. The E. C. increases from 0.95 mmohs/cm. at 25° C. to 2.1 mmohs/cm at 25° C. at a depth of 120.160 cm. This level of soluble salts was found not to affect the use of the land for the production of a salt tolerant crop like cotton. However saline patches do occur in the plain and restrict the yield of cotton as well as other crops.

Cation exchange capacity values range from 58 meq/100 gm. to 75 meq/100 gm. in Kenana. The cation exchange capacity as shown in Appendix Tables XVII-XIX follows closely the distribution of clay in the profile. The high CEC indicates the montmorillonitic nature of these clays. However the correlation found between the CEC and the percentage of clay (approximately 1 meq/1 gm. clay) is probably due to coincidence in the proportions of the previously cited clay minerals rather than to montmorillonite alone.

The exchangeable Na is relatively higher in the Gezira site than in Kenana profile. In both soils it increases with depth to a maximum at about 70 cm. in the Gezira and about 80 cm in Kenana. These maxima indicate 21% (ESP) in the Gezira and 20% (ESP) in Kenana. Below these maxima it remains almost constant with depth in the Kenana profile and either increases or decreases in the lower horizon of the Gezira soil. A value of 25% exchangeable sodium percentage was obtained in the C horizon of this soil. Under this high level of exchangeable sodium the poor drainage of the soil is expected as a result of dispersing of the fine fraction. According to Green (20) the imperfect internal drainage of these soils is responsible for their lower fertility as compared to other similar areas in the world. Cotton as reviewed earlier is a tolerant crop to alkalinity and salinity and reduction in yield may probably be due to a deteriorated physical condition of the soil rather than to Na toxicity. The data also indicated that the ESP is less than 15% in the top two feet of the two profiles which may permit some permeability and leaching processes. Gypsum applications were early found useful in promoting deeper moisture penetration.

Despite the dark color of the epipedons of the two profiles (10YR 4,3/2 for the Gezira and 10YR3/2 for Kenana) the data clearly indicated that both soils are very low in organic matter. With the exception of the surface mulch of Kenana profile (approximately 2 cm thick) all horizons of the two soils have less than 1% organic matter. This content is considerably lower than that reported for the American Grumusols; Beaumont, Lake Charles, Victoria, San Saba and Houston Black Clay. However the Regurs of India and the Tirs of Morocco are similarly characterized by a low organic matter content (32).

Free iron oxides were determined at selected depths in the two profiles and the results are shown in Table XIV and XV. The percentage of extractable iron did not show any significant variation with depth. In the Gezira it ranges from 1.2% to 1.8%. The Kenana content of free iron oxides is higher than that of the Gezira, being in the range of 2.7%. The data did not indicate any relation between extractable iron and the color of the three layers in the profile. However the form of iron in addition to several other substances, mainly quartz, kaolinite, carbonates of lime and magnesium, gypsum and various salts may cause variation of color in the soil profile. However, this is not always the case and the color of a soil horizon could be inherited from the parent material, since the color of some rocks may persist for centuries even under adverse conditions (41).

The soluble cations and anions of all horizons of the two profiles are given in Tables XII and XIII. These data were mainly presented here to reflect the moisture migration in the soil profile. To do this, two values were calculated; soluble sodium percentage (SSP) and total soluble cations (TSC). The method of Miller and Ratzlaff (35) was consulted in this investigation. The interpretation of the results however may be limited by the fact that sampling was not done in contiguous increments small enough to differentiate small variables in moisture migration as recommended by the authors cited above, otherwise the procedures were exactly the same. The gradual increase in SSP with depth in the two profiles is evident and indicates the direction of moisture migration with the exception of one sample collected from the surface of the profile the SSP increases steadily from 37.5% to reach a maximum of 68.5% at a depth of 140.175 cm in the Gezira. In Kenana it increases from 60% to 87% from the surface of the profile to a depth of 160-200 cm. The results obtained from the TSC indicated a general increase from 3.8 meq/L, saturation extract to 77 meq/L at a depth of 175-200 cm in the Gezira profile and from 5 meq/L to 19 meq/L at a depth of 120, 160 in Kenana. The concomitant increase in both total soluble cations and soluble sodium percentage values was called by Miller and Ratzlaff (35) salt precipitation. It indicates that moisture could migrate only under high head pressures and in thin films through that portion of the profile which reflects this spontaneous increase of (SSP) and (TSC) with depth. The salt precipitation was assumed to take place as moisture is dissipated from the soil, rather than as the soil is initially wetted. The picture is also complicated by the presence of cracks. Moisture may accumulate at the base of the crack and then migrate into dried soil interrupting the general trend of the chemical imprint observed in the profile.

The occurrence of chloride in the Kenana profile may reflect the effect of cracks in this chemical imprint. The chloride content of the bottom layer showed a steady increase below a depth of one meter. Above this depth which is usually reached by the cracks from the surface the trend was almost reversed. The chloride content increases upwards i.e. decreases from the surface to the region reached by cracks. This trend may indicate that chloride is being removed from the surface and deposited in the lower depths of the profile. However, as water accumulates in the bases of cracks it migrates by capillarity upwards, as well as in other directions, and carries the chloride with it. This mode of chloride occurrence was less obvious in the Gezira profile. The above hypotheses could be tested in controlled field studies and the conclusions drawn from this interpretation are tentative.

Soil Genesis and Classification

Due to the churning process and the fine texture of the soil, difficulty has long been encountered in attempting to designate genetic horizons of the profile of the Central Clay Plain soils. Therefore, the morphological trends observed in these two profiles were probably a result of depositional processes as well as of soil forming factors. Despite this difficulty the two soils could be classified as Vertisols. This classification was already adopted by most soil scientists in the Sudan and it can be confirmed from the following characteristics:

high content of montmorillonitic clay minerals, more than 52 percent clay; more than 54 milliequivalents exchange capacity; wide and deep cracks; high coefficient of expansion; common slickensides and parallelepiped structure; occurrence of gilgi micro relief in some non-cultivated Gezira soil. Their lower categories are given in the following classification according to the 7th Approximation, Supplemented 1967:

	Central Gezira, Tebub Block, Pit B
Order	Vertisol
Suborder	Usterts
Great Group	Chromusterts
Subgroup	Typic Chromustert
Family	Very fine clay, montmorillonitic, hyperthermic
7th Approximation name	Very fine clay, montmorillonitic, hyperthermic, typic chromustert

	Kenana Pit KP03
Order	Vertisol
Suborder	Usterts
Great Group	Chromusterts
Subgroup	Typic Chromustert
Family	Very fine clay, montmorillonitic, hyperthermic
7th Approximation name	Very fine clay, montmorillonitic hyperthermic, typic chromustert

CHAPTER V

SUMMARY AND CONCLUSION

The chemical, physical and mineralogical properties of the two soils were found very similar. Their similarities were reflected in their classification. Both soils have been classified as very fine clay, montmorillonitic, hyperthermic, typic chromustert. Slight differences in color, texture and degree of weathering were observed. The clay mineralogy of the two soils appears to be dominated by montmorillinite which in some horizons is interstratified with vermiculite. Kaolinite was found to occur in all horizons in variable amounts and in lesser quantities than montmorillonite. Illite was present in the least amount of all clay minerals present in these clays. The higher clay content of Kenana was associated with greater capacity of this soil to hold water and to swell and shrink when wet and dry than the Gezira soil. Under these conditions it is expected to have a more intense cracking pattern than the Gezira. The slight difference in the chemical properties of the two sites followed the general trend that soils to the South of the Plain are of lower salinity, lower alkalinity and less calcareous than the soils in the North.

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APPENDIX

TABLE XVI

THE MINERALOGICAL ANALYSIS OF THE HEAVY FRACTION (S.G. > 2.9) OF THE GEZIRA SOIL, PLOT 141 GEZIRA RESEARCH FARM

Depth cm	Tourmaline	Zircon	Garnet	Rutile	Zoisite	Titanite	Stauralite	Kyanite	Enstatite	Silliminite	Epidot	Hornblend	Actinolite	Augite	Hypersthene
0-2	-*	+**	5	+	+	1	+	-	+	-	28	55	-	11	-
2-40	-	1	4	1	3	+	+	2	-	-	37	45	-	6	1
40-60	+	+	1	1	2	1	+	-	-	2	34	34	2	12	+
60-90	+	+	+	+	1	+	+	1	-	+	45	46	+	7	-
90-110	-	+	2	+	1	3	1	+	+	+	34	53	1	5	+
110-130	+	+	1	+	2	1	1	+	+	1	25	58	+	11	-
130-165	1	+	2	+	+	1	-	1	-	1	38	51	-	5	-
165-185	+	1	+	1	+	2	1	-	-	1	35	54	2	3	-
185-220	-	2	1	1	1	+	-	+	-	-	33	52	1	9	-

* - = nill
** + = trace

Source: Gezira Profile Investigation 1963 by L. H. Ochtman. Miscellaneous Paper No. 2, Soil Survey Division of Sudan Dept. of Agric., Wad Medani, Sudan.

TABLE XVII

SELECTED CHEMICAL AND PHYSICAL DATA ON SOILS OF
UNIT 13, KENANA PIT KP03

Depth cm	Particle Size Distribution on Fine Soil % C.S.	% F.S.	% Silt	% Clay	CEC meq/100 gm	ESP	% Saturation	% Nitrogen	% Organic Carbon	C/N
0-2	7	12	20	60	61	5.0	85	0.035	0.65	18.5
2-20	6	11	20	61	63	6.0	78	0.031	0.54	17.5
20-60	5	10	20	63	63	14.5	78	0.021	0.44	21.0
60-100	5	9	19	65	64	20.0	77	0.017	0.43	25.0
100-120	5	8	20	66	68	20.0	91	0.016	0.44	28.0
120-160	4	9	19	66	69	20.0	100	0.013	0.42	32.0
160-200	4	8	19	64	71	21.0	106	0.017	0.54	32.0

TABLE XVIII

SELECTED CHEMICAL AND PHYSICAL DATA ON SOILS OF UNIT 13, GEZIRA, SULEIMI BLOCK PIT B

Depth cm	Particle Size Distribution on Fine Soil % C.S.	% F.S.	% Silt	% Clay	CEC meq/100 gm	ESP	% Saturation	% Nitrogen	% Organic Carbon	C/N
Surface mulch	5	11	24	54	56	1.5	71	0.041	0.61	15.0
0-45	7	11	20	57	57	4.5	65	0.016	0.30	18.5
45-60	5	9	21	58	59	12.0	65	0.014	0.31	22.0
60-85	6	10	20	57	58	17.0	70	0.012	0.29	24.0
85-140	4	9	23	59	62	17.0	84	0.013	0.75	27.0
140-175	3	8	21	60	60	12.5	81	0.011	0.32	29.0
175-200	5	9	20	54	53	13	75	0.008	0.16	20.0

TABLE XIX

SELECTED CHEMICAL AND PHYSICAL DATA ON SOILS OF
UNIT 13, GEZIRA, TEBUB BLOCK PIT B

Depth cm	Particle Size Distribution on Fine Soil % C.S.	% F.S.	% Silt	% Clay	CEC meq/100 gm	ESP	% Saturation	% Nitrogen	% Organic Carbon	C/N
0-2	5	8	15	68	58	10.0	78	0.002	0.27	13.5
2-55	12	11	18	55	54	8.0	102	0.034	0.26	7.7
55-80	6	8	19	60	60	21.0	88	0.017	0.23	13.5
80-110	4	7	17	69	71	17.0	113	0.016	0.42	26.0
110-140	9	3	21	60	74	22.0	121	0.019	0.53	28.0
140-155	3	7	18	60	75	17.0	117	0.018	0.37	21.0
155-190	11	7	17	59	61	25.0	58	0.010	0.32	32.0

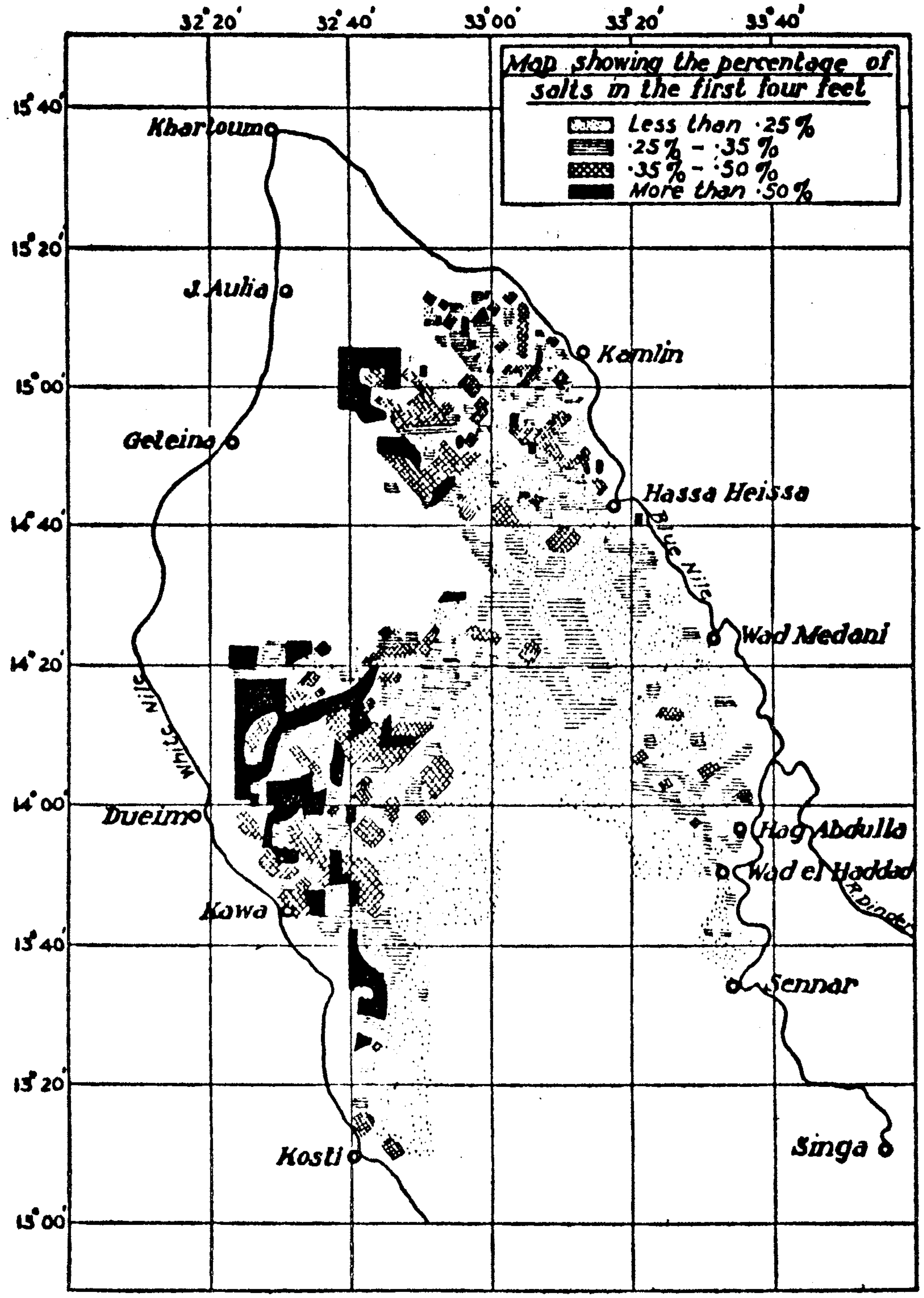

Figure 8. Percentage of Easily Soluble Salt in the Top Four Feet of the Gezira Soil After Tothill. (Agriculture in the Sudan. London Oxford University Press. Geoffrey Camberlege. 1948)

VITA

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